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PETROLEUM IN BORNEO.[1]

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[1] Published by permission, the Director, U. S. Geological Survey. This paper is one of a series of critical reviews which the author is making of geologic and geographic literature pertaining to foreign oil fields. *Editor.*

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INTRODUCTORY STATEMENT.

History of Development.—For centuries the natives of Sumatra, Java, and Borneo have used mineral oils, obtained from surface seepages, for various domestic purposes and especially as a remedy for skin diseases. In 1853 Motley noted seepages on the Island of Labuan, in the British Borneo and ten years later Menten found seepages on Tarakan Island, off the east coast of Dutch Borneo.

In 1866 a shallow well was drilled on Labuan Island, which gave a small flow of oil for at least thirteen years. Collingwood in 1867 described a petroleum spring in British North Borneo and stated that others were known. About 1887 there were three small producing wells on the Klias Peninsula, opposite the town of Brunei.

The first geologic investigation of the Dutch East Indian oil fields was made in 1883 when the geologists G. P. A. Renaud and R. Fennema were sent by the Bureau of Mines at Batavia to examine the prospective fields of Lower Langkat, in the East Coast Residency of Sumatra. The oil fields of Java were investigated in the next decade by R. D. M. Verbeek and R. Fennema. The coal and oil occurrences of Koetei, in the South and East Coast Residency of Borneo were first described by J. A. Hooze in 1888.

The pioneer in the exploitation of petroleum in Borneo was the Dutch mining engineer, J. H. Menten, who in 1863 explored Tar-

akan Island and later the Koetei region. Menten obtained in 1888 the Louise Concession at the mouth of Mahakkam River, in Koetei, and in 1891 the Mathilde Concession at Balikpapan. In 1897 he commenced drilling in the Sanga Sanga field. Oil was struck at 190 feet.

The Menten concessions were transferred in 1898 to the Nederlandsch-Indische Industrie en Handel Maatschappij, which was founded that year, under the control of the Shell Transport and Trading Co., of London. The amalgamation of the Shell Transport and Trading Co., on January 1, 1907, with the Koninklijke Nederlandsche Maatschappij tot Exploitatie van Petroleumbronnen in Nederlandsch Indië (Royal Dutch Company for the Working of Petroleum Wells in Netherlands India) brought the Nederlandsch-Indische Industrie en Handel Maatschappij under the control of the new Royal Dutch-Shell group.

Commercial drilling in Borneo began at Sanga Sanga in 1899. Thirty-four wells were drilled of which 25 were productive. A production of 700 metric tons a day was soon obtained. A refinery with a capacity of 2,000 metric tons a day was built at Balikpapan.

The exploration for oil extended to British North Borneo, where the Bombay-Burmah Trading Co. obtained the Korszki Concession, and drilled with varying success in British North Borneo, Brunei, Sarawak, and on Labuan Island. The firm of Buiju also drilled on Labuan without success.

Production.—In spite of the development of new fields in Ceram and in Sumatra, the island of Borneo has contributed since 1910 an increasing proportion of the total output of crude petroleum in the Dutch East Indies. In 1910 Dutch Borneo produced 42 per cent. of the total production of the Dutch East Indies; in 1920 its percentage had risen to 61.5 per cent. Taken together, British and Dutch Borneo in 1920 yielded 63.8 per cent. of all petroleum won in the entire Archipelago.

The production of crude petroleum in British and Dutch Borneo in comparison with the total production of the East Indian Archipelago is shown by the following table:

TABLE I.

PRODUCTION OF CRUDE OIL IN BORNEO AND THE EAST INDIES.

	Dutch Borneo,[2] Metric Tons.	British Borneo, Metric Tons.	East Indies (Incl. British Borneo), Metric Tons.
1910.....	633,472	.....	1,500,245
1911.....	814,707	.....	1,670,568
1912.....	672,438	5,534[3]	1,524,939
1913.....	766,687	30,562[3]	1,564,785
1914.....	866,718	65,185[3]	1,634,405
1915.....	893,890	67,000[3]	1,710,443
1916.....	957,395	90,067[3]	1,820,251
1917.....	869,262	77,604[3]	1,870,214
1918.....	999,426	72,511[3]	1,836,712
1919.....	1,372,006[3]	85,695[3]	2,245,562
1920.....	1,455,228	146,729[3]	2,512,049

GENERAL FEATURES OF BORNEO.

Political Divisions.

Politically, the control of the island of Borneo is divided between Great Britain and the Netherlands.

The British portions of Borneo constitute a little over one fourth of its entire area. These consist of the Rajahship of Sarawak, a protectorate of Great Britain; the Sultanate of Brunei, under the administration of a British Resident; British North Borneo, under the jurisdiction of the chartered British North Borneo Company; and the Island of Labuan, which is incorporated with the Straits Settlements. The Governor of the Straits Settlements is *ex officio* High Commissioner of Brunei and British Agent for British North Borneo and Sarawak.

Dutch Borneo is divided politically into the Residency of the Western Division (Wester Afdeeling), and Residency of the South and East Division (Zuid- en Ooster Afdeeling). Both Residencies are subdivided into a number of native sultanates and principalities, each under the supervision of a Dutch assistant resident or a *contrôleur*.

[2] Jaarboek van het Mijnwezen in Ned. Oost-Indië, Batavia.
[3] Annual reports, Royal Dutch Company.

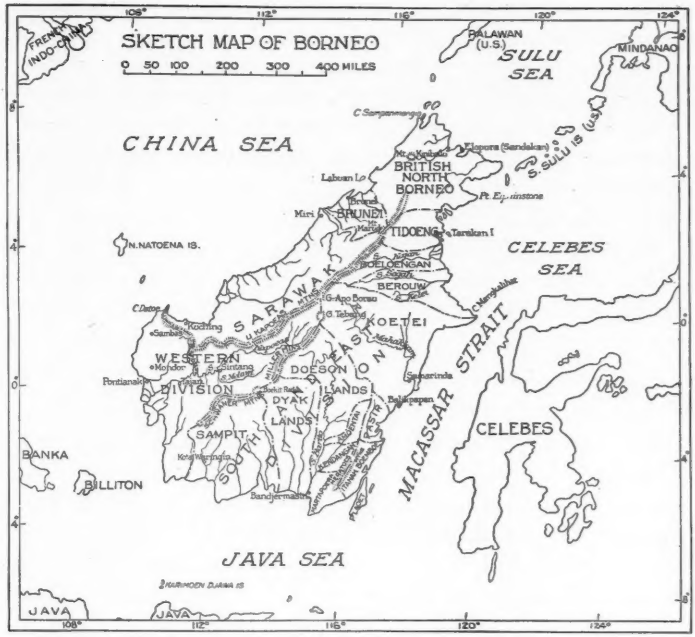

FIG. 33.

Physiography.

From a central mountain mass a series of mountainous divides branch radially, separating the island of Borneo into western, southern, northern, and eastern basins. The central mountain mass of Borneo, lying between 1° 20′ and 2° 20′ north latitude, extends northeast-southwest. Its highest peaks are Goenoeng[4] Tebang and Goenoeng Apo Borau. The radiating divides consist of short isolated ranges or ridges, which follow one another in the direction of the assumed tectonic lines of the island. The Schwaner Mountains are a typical example. These isolated mountain ridges, surrounded by low undulating country, are characteristic of Borneo, both in the principal and subordinate ranges

[4] Goenoeng (pronounced "goonoong") in Malay means "mountain."

and their numerous spurs. This unusual type of upland forms the entire watershed between Koetei and South Borneo.

The hills which surround the mountain ridges form aggregates of small, rounded or extended hills, many of which are very steep. Their average height does not exceed 200 or 300 feet, except close to the divides where they are higher and give the country a more mountainous appearance. Isolated outliers of the hill-country appear in the plains.

The hill-land is succeeded by low-lying plains, which, especially in South Borneo, are of great extent. The dry plains are succeeded in turn by swamp-land at the deltas of the large rivers and along the coast. (Fig. 33.)

Areal Geology.

The known geology of the island of Borneo is complicated. According to the Abendanon map, only three areas of Dutch Borneo, widely separated, have been thoroughly investigated geologically. One comprises the greater part of the Western Division of Borneo, which was explored by Molengraaff in 1893–1894. The second lies southeast of a line running from Bandjermasin to Cape Santang. The third area occupies the two prominent peninsulas which mark the northeast coast of Dutch Borneo. About three fourths of the remainder of the Dutch possessions is known through reconnaissances only, and several extensive areas are geologically unexplored.

The observations which have been made of the British portions are for the most part disconnected and uncorrelated. In the absence of a detailed geologic survey of any part of British Borneo, the isolated observations leave many problems unsolved. Fortunately the more complete knowledge of the Dutch area is of considerable help in interpreting the geology of the British provinces of Borneo.

The core of the axial mountain range, which separates Dutch from British Borneo, consists of granites, gabbros, and intensely folded schists. These rocks have been referred to the Archean,

but their precise age is undetermined, and some of the schists may be metamorphosed sediments of a much later geologic date. The igneous rocks probably belong to more than one period.

The "old slates" consisting of bluish phyllites and siliceous slates of undifferentiated Paleozoic or perhaps Mesozoic (?) age flank the principal granitic and crystalline axis of the island. The Upper Kapoeas chain, which extends almost east and west between Western Borneo and Sarawak, consists of these rocks.

Phyllites occur on the upper Berouw or Kelei River and the lower Kajan or Boeloengan River, and granites on the upper Segah and Kelei Rivers, where they form the cores of the so-called "Sambalioeng coulisses."

A zone of limestones, 20 to 40 miles in width, extends in the foothills of British Borneo from longitude 112° east (Greenwich) nearly to Marudu Bay. These were regarded by Posewitz as belonging to the Carboniferous, but the identification of the fossils upon which this reference is based is by no means complete. It is probable that some indeed if not all of the so-called "Carboniferous limestones" of Posewitz and Tenison Woods, is of Mesozoic age.

Immediately south of Kapoeas Range the "Danau formation" occurs, faulted down against the Paleozoic slates. Fossils, especially *Radiolaria,* found in the "Danau formation" indicate that it belongs to the Jurassic, but it is possible that older Mesozoic beds are included in it. No corresponding radiolarian beds have so far been described as occurring in British Borneo.

Fossils of the Lias epoch (Lower Jurassic) were found in a shale formation in the Sambas district of the Western Division of Dutch Borneo, immediately south of Sarawak. The Liassic shales are overlain by a sandstone and shale series, containing fossils characteristic of the Dogger epoch (Middle Jurassic). At the western end of Sarawak fossils of the Middle Oölite (Upper Jurassic) have been found in a limestone formation. Cretaceous rocks have not been recognized *in situ* in British Borneo. In the Western Division of Dutch Borneo the Cenomanian stage (Middle

Cretaceous) occurs to the east of Sintang. The Cretaceous formations of the Western Division extend in an irregular bifurcated belt in a generally easterly direction from the upper Sekajan (or Kapoeas) valley to the foot of the Müller Range. Cenomanian limestones and crystalline schists, which are considered to be metamorphosed Cenomanian sediments, form the core of the Meratoes Mountains. The Alino and Waringin shales of South and East Borneo are referred to Senonian stage of the Upper Cretaceous; but older rocks are in all probability included. These flank on both sides the metamorphosed Cenomanian rocks of the Meratoes Mountains.

Mesozoic (?) granites and contact-metamorphic rocks form the south slopes of the Schwaner Mountains. Granite massifs of Mesozoic age may be traced from Mandor to Tajan on Soengei[5] Kapoeas.

Volcanic rocks appear chiefly in the Müller Mountains. In the western portion of the range, andesites, quartz-andesites, and porphyrites predominate. The central portion consists of terraced table mountains, separated by deep valleys. The table mountains consist of thick beds of tuff, in places alternating with horizontal or almost horizontal flows of andesite or basalt. In the eastern part of the Müller Mountains acid rocks, chiefly rhyolites, quartz-andesites, and mica-quartz-andesites, predominate. A line of porphyrite cones extends in an almost east-and-west direction on the gently sloping sandstone plateau which forms the northern slope of the Schwaner Mountains. A zone of andesite and dolerite hills, about 11 miles wide, bearing about N. 80° E. occurs in the extensive granite area of Sambas.

In Dutch Borneo, Tertiary sediments occupy the middle portions of the Kapoeas River and Melawi River valleys. The greater part of the South and East Division of Borneo is underlain by Tertiary sediments, intruded locally by Tertiary and younger igneous rocks. Quaternary deposits occupy the coastal areas of the south and west coasts and river valleys of southeastern Borneo.

[5] *Soengei* in Malay means "river."

The Tertiary region of British Borneo forms a coastal zone, about 60 to 100 kilometers (36 to 62 miles) wide.

Tectonics.

General Discussion.—Two well-defined faults bound on the north and south a "West Borneo horst" of pre-Tertiary phyllites, slates, and crystalline rocks. This horst constituted, in the opinion of Van Es, a buttress against which crustal movements were exerted with little effect upon it other than slightly increasing its elevation.

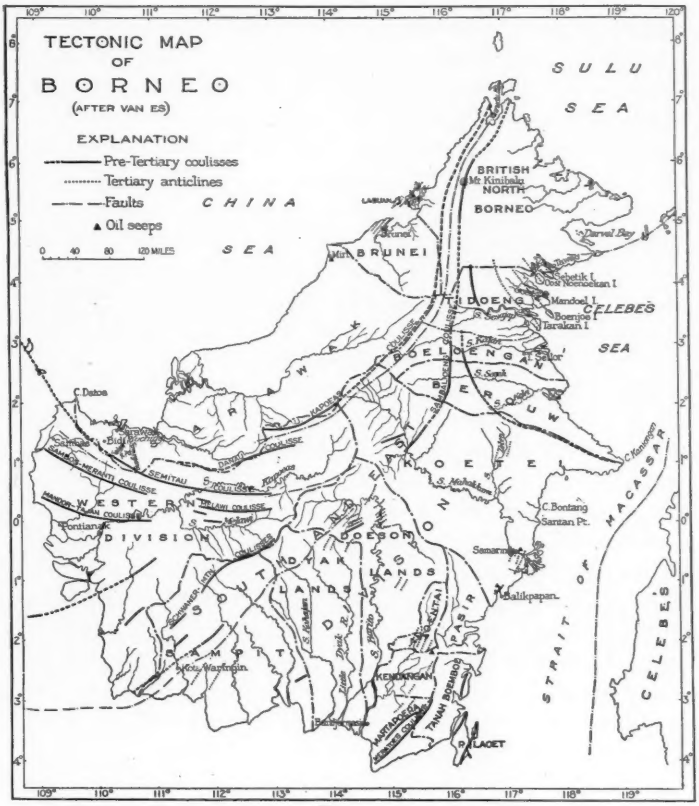

FIG. 34.

On the northwest coast, in British Borneo, and along the east and south coasts of Dutch Borneo are areas of Tertiary sediments which have been considerably affected by Tertiary folding movements. (Fig. 34.)

It is evident from the stronger folding which the Lower Miocene, Oligocene, and Eocene beds of the South and East division show as compared with the Upper Miocene and Pliocene beds that a period of folding took place between the deposition of the Lower and Upper Miocene. This is particularly evident in the vicinity of Balikpapan Bay. The Miocene folding was followed after an interval by an Upper Pliocene folding along the same axes. In contrast, a large part of the Tertiary of the Western Division of Borneo was left almost undisturbed by both the Miocene and the Upper Pliocene folding.

Pre-Tertiary Structure.—The structure of Borneo shows an intimate relation to that of its neighboring islands. The inner geanticlinal arc of the Philippine Islands extends southwards through the Borneo Horst, in a broad curve nearly parallel to the west coast of British Borneo from the northernmost point of the island. From central Borneo the direction changes gradually first to the west and then to the northwest to Cape Datoe, and continues in the North Natoena Islands.

The existence of the geanticlinal arc is evidenced in Borneo by the occurrence of a series of coulisses. As has been explained in a previous paper,[6] the name "coulisse" is applied to one of a series of structural ridges arranged *en échelon* on the earth's surface, like the wings of the stage (French, *coulisse*) in a theater. Such features are formed by folding of the stratified rocks and the intrusion of masses of igneous rocks, followed by erosion. These echeloned ridges form a prominent part of the physiography not only of the Dutch East Indies, but of the Malay Peninsula, Burma, French Indo-China, and the Philippine Islands as well.

The coulisses of Borneo show in their arrangement a phenomenon which has been noted in less degree in Java and Sumatra and

[6] Redfield, Arthur H., "The Djambi Oil Field of Sumatra," *Eng. and Min. Jour.*, Vol. 112, No. 24, pp. 939–943, New York, December 10, 1921.

in greater degree in the Philippine Islands, namely a branching out or virgation of their members. Though in the north of Borneo all coulisses appear to be compressed into a narrow zone and to follow generally a north-northeast direction, in the south they radiate fanwise. The most easterly members curve to the southeast and turn in the direction of Celebes, and probably are continued in the mountain ranges of that island. The northern portions of the Meratoes and Poeloe[7] Laoet coulisses trend north and south, but the southern portions curve to the southwest, and continue in the coulisse of the Karimoen Djawa Island, and probably certain of the coulisses of eastern Sumatra. The central series of coulisses, to which the Schwaner Mountains belong, trend from southward to southwestward, to westward, and finally to northwestward, and continue in the Banka-Malacca horst. The Mandor-Tajan, the Sambas-Meranti, the Semitau, and Danau coulisses have the same curvature but with a shorter radius, and may be followed through the Anambas and Natoena Islands to the eastern coastal range of Annam. The Upper Kapoeas coulisse is the innermost of these arcs and has in consequence the shortest radius.

Tertiary Anticlines.—Tertiary anticlines have been noted in several widely separated localities of Borneo. Our present knowledge of the geology of the island is not sufficiently advanced to permit any exact correlation of their axes. Their close parallelism with the main tectonic lines of the island is notable.

A group of anticlines whose axes trend northeastward has been noted on the Peninsula of Brunei. A second series, apparently a continuation of the first, crosses the Island of Labuan and the Klias Peninsula opposite Brunei. Four anticlines, whose axes trend northeastward, occur to the southeast and east of Kota Waringin. The anticlinal axes parallel the Schwaner Mountain coulisse and the Schwaner Mountain fault. Similar groups of Tertiary anticlines cross the upper valleys of Kahajan and Barito Rivers, paralleling with their axes the tectonic lines of the Schwaner Mountains.

[7] *Poeloe* in Malay means "island."

The Meratoes and Poeloe Laoet coulisses in southeastern Borneo are paralleled north of Bandjermasin by a series of Tertiary anticlines whose axes bear north-northeastward to northward. This trend is continued by the Balikpapan anticline, by a group of four anticlines which cross Mahakkam River above and below Samarinda, and by two anticlines in the upper valley of Soengei Telen.

The anticlinal axes which cross Tarakan and Sebetik Islands to the mainland and continue into British territory trend from southeast to northwest. This trend is parallel to the observed and assumed trend of the coulisses of this region.

Faults.—The two principal faults of the island of Borneo which bound the West Borneo Horst are longitudinal with regard to the main tectonic lines of the archipelago. The first of these, the Upper Kapoeas fault, bounds the Upper Kapoeas Mountains on the south side and separates the Paleozoic phyllites of which the mountain range is composed from the Mesozoic rocks of the Danau coulisse. The second fault line, with which volcanic rocks are associated, bounds the Schwaner Mountains on the south. Between the two main faults lies a parallel dislocation upon which the Mountains have been formed by eruption.

Two faults, longitudinal to the main axis of the island in one extremity, and transverse in the other, have been assumed. Macassar Strait is believed by Van Es to conceal a fault-line which runs northward from Java Sea and curves northeastward into Celebes Sea. A second fault has been traced from Pt. Elphinstone, through the Sulu Islands of the Philippine Archipelago into Mindanao. Though transverse at its southern end to the principal coulisses and faults of Borneo, in the Philippine Islands it is longitudinal with respect to the main tectonic axes of Malaysia in general.

Vulcanism.—Probably as a consequence of the fault movements described above, igneous eruptions have occurred along certain faults. These date probably to Miocene time, when the folding in other parts of the island was strongest.

Oil-bearing Areas.

There are at present three important oil-producing areas on the island of Borneo. The first is the Koetei district, extending from the mouth of Mahakkam River southwards toward Balikpapan Bay. The second is the Tarakan district, situated on Tarakan Island off the east coast, about 80 miles south of the British-Dutch frontier. The third is the Miri district, on the west coast of Sarawak, about 150 miles south of Brunei Bay.

The Koetei Oil District.

Location and Extent.—The Koetei oil district lies in the Landschap of Koetei, the southernmost of the subordinate divisions of the Afdeeling of Koetei and the Northeast Coast, Residency of the South and East Coasts, Dutch Borneo. It includes the Sanga Sanga field in the Louise Concession; the Sambodja field in the Nonny Concession, and the Moeara field in the concession of the same name. (See Fig. 35.)

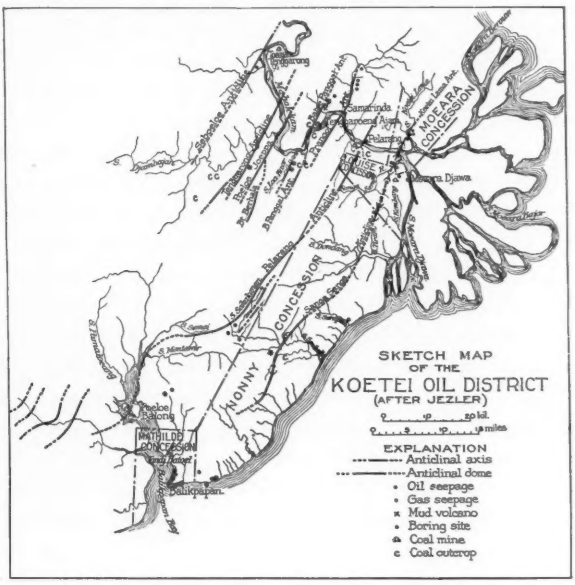

FIG. 35.

Physiography.—The Mahakkam or Koetei River, flowing eastward, divides at a point about 25 miles from the coast into three distributaries, the Moeara[8] Djawa to the south, the Moeara Bajor to the southeast, and the Moeara Berau to the north. East of Moeara Djawa and Moeara Berau there is a broad swampy delta, overgrown by mangroves, and inhabited by a few natives. West of those rivers a peneplain, whose hill-ridges do not exceed 200 feet in altitude, extends for a considerable distance. Farther west, beyond Pelarang, the peneplain merges into a low hill-country whose maximum elevations are about 500 feet.

The peneplain west of Moeara Djawa and Moeara Berau, about 12 miles wide, cuts across folded Tertiary sediments which strike about N. 20° E. The principal streams of this region cut the folds at about right angles; the tributaries run parallel to the folds.

Areal Geology.—The coastal region of Koetei is underlain by a zone of folded Tertiary sediments, about 60 miles wide, which consist principally of post-Eocene formations, chiefly Miocene. The occurrence of Eocene rocks, so far as is now known, is restricted to the middle portion of the Mahakkam valley, and their geologic relation to the later Tertiary deposits is not wholly determined.

Aquitanian and Lower Burdigalian (Lower Miocene) beds are exposed in the cores of the eroded anticlines. They occur, 4,900 feet thick, in South Koetei, west of Balikpapan Bay, and in the Lower Mahakkam valley. In the vicinity of Cape Bontang and Santan Point only a small part of these stages, not over 820 feet in thickness, is exposed on the surface.

Upper Burdigalian and Vindobonian formations occur flanking the Lower Miocene beds near Balikpapan Bay, on the lower Mahakkam, and in Bontang. The Pontian (uppermost Miocene) beds constitute the uppermost beds of the synclines, below the recent accumulations of surface material.

Stratigraphy.—The Tertiary of eastern Koetei consists of a very thick series of sediments, whose oldest members were de-

[8] Moeara (pronounced Mooahra) in Malay means "river mouth." Moeara Djawa may be translated "Java Mouth" or "Java Pass."

posited probably in the transition stage between Lower and Upper Tertiary, while the youngest members border on the Pliocene. They were apparently laid down under delta conditions and changes of facies are numerous.

The Eocene is represented on the middle Mahakkam by the "plateau sandstone." This formation consists at its base of quartz-conglomerates, overlain by quartz-sandstones, shales containing plant impressions, and coal seams. The evidence of fossils, as well as its lithologic similarity to the Eocene formations of southeastern Borneo, places the "plateau sandstone" in the Eocene. This formation is overlain unconformably by orbitoid limestones of Aquitanian (lowest Miocene) age.

For the greater part of Koetei no detailed stratigraphic division of the post-Eocene has been made. Rutten has subdivided the formations of Balikpapan into stages, and Jezler has correlated the formations of the lower Mahakkam with Rutten's subdivisions. But the numerous changes of facies even in the same area make correlation difficult, and for most of Koetei only a rough division of the post-Eocene beds into three major stages is feasible.

The oldest Tertiary sediments appearing on the lower Mahakkam belong to the Aquitanian stage. These formations, named by Jezler the Prangat beds, consist of 1,100 meters (3,600 feet) of limestones, shales, concretionary clays, and orbitoid limestones. They contain at Sanga Sanga traces of natural gas without petroleum.

The Prangat beds of the lower Mahakkam valley are correlated by Jezler with the Pamaloeang beds of Balikpapan Bay, described by Rutten. The latter are composed of gray and brown, hard concretionary shales, indistinctly bedded and in places marly; thin-bedded gray sandstones containing scales of coal between the bedding planes; Aquitanian (orbitoid) limestones; and impure limestones with corals. The almost total absence of coal seams is a distinguishing mark of this stage. The thickness of the Pamaloeang beds of Balikpapan Bay is about 1,500 meters (4,290 feet).

The Prangat beds are conformably overlain by the Sanga Sanga beds which belong to the Burdigalian stage of the Lower Miocene. The latter are composed of about 1,300 meters (4,260 feet) of sandy clays and shales and impure limestones. The Sanga Sanga beds contain the oil horizons of Sanga Sanga and Sambodja, and correspond to the Poeloe Balang beds which form the oil-bearing formations of Balang Island in Balikpapan Bay.

In the Poeloe Balang strata, of Burdigalian (Lower Miocene) age, shales are few; sandstones are numerous. The shales are hard and gray; the sandstones vary from soft to hard. Extensive limestone and marl beds occur. Numerous seams of black, lustrous coal, breaking with a conchoidal fracture, and without inclusions of mineral resin, occur.

The Moeara Djawa beds of Vindobonian (Upper Miocene) age conformably overlie the Sanga Sanga beds on the lower Mahakkam. These consist of light-gray clays and sandstones, attaining a thickness of about 800 meters (2,640 feet). This stage contains the oil of Moeara Djawa.

The Moeara Djawa beds are considered by Jezler to correspond with the Mentawir beds of Balikpapan Bay. These consist of gray sandstones and clay, with interbedded lignites. The associated lignites are somewhat resinous.

The Pontian stage (uppermost Miocene) is represented in the Sanga Sanga field by the Kembang beds, which are composed of 800 meters (2,640 feet) of gray and red sandy clays, ferruginous sandstones, and dull black to brown lignites containing resin. This is the oil-bearing stage of Balikpapan Bay.

The Pliocene is not represented in the formations of Koetei. The Tertiary sediments are overlain unconformably in places by Quaternary sediments of varying thickness, up to 400 meters (1,320 feet).

The post-Tertiary deposits of eastern Koetei consist of coralline sands along the coast and on the offshore islands; clays, shaly clays, sands, and gravels in the river valleys; and perhaps moor formations in the deep swamps which border the rivers. Local deposits of calcareous tuff occur.

Geologic Structure.—The Tertiary of the Lower Mahakkam is folded into several anticlines whose major axes strike about N. 20° E.

The easternmost of these anticlines, known as the Sanga Sanga anticline, may be traced for about 50 miles from Koetei Lama River almost to Balikpapan Bay, where it flattens and disappears in the Pontian (uppermost Miocene) strata. At the crossing of Sanga Sanga River and in the center of the Louise Concession domes occur, on the crest of which the Sanga Sanga beds are exposed. The outcropping of the Moeara Djawa beds at Soengei Tiram to the south indicates the dipping of the anticlinal axis at that point. A third dome occurs in the middle of the Nonny Concession on Soengei Sambodja.

Five miles upstream the Pelarang anticline occurs. North of Mahakkam River it parallels the trend of the Sanga Sanga-Koetei Lama anticline, but south of Mahakkam River it diverges to the southwest, swinging finally in a semicircle to the head of Balikpapan Bay and across Poeloe Balang to the southwest. The limbs of the Pelarang anticline dip more steeply than those of the Sanga Sanga anticline. On Mahakkam River the lower horizons of the Sanga Sanga beds form a "closed" dome, while on Poeloe Balang the anticline is "open." On Balang Island the Sanga Sanga beds are isoclinal, and are unconformably overlain on the east by horizontal Pontian sediments. On the west the Pemaloeang-Prangat beds are faulted down against the Sanga Sanga beds.

Between the Samarinda and Tenggarong a group of five anticlinal axes crosses Mahakkam River. The intensity of the folding increases to the west, so that the more westerly anticlines are more and more closed and expose older geologic horizons on their crests.

On the western limb of the flat syncline which succeeds the Pelarang anticline to the west, east-dipping Sanga Sanga and Prangat beds which form the eastern limb of the Prangat anticline occur for wide stretches near Samarinda. These Prangat beds, dipping steeply to the east, are faulted down to the west against Upper Miocene (Vindobonian and Pontian) formations.

The western limb of the Prangat anticline has accordingly subsided and the steeply dipping eastern limb has been overthrust upon it. This is known as the "Samarinda Fault."

The Soengei Loa Haor lies west of the Boekit Panggal anticline in a broad syncline in which the Sanga Sanga beds predominate. This syncline is adjoined on the west by the Berhala, Poeloe Joepa, and Tenggarong anticlines. These steeply dipping anticlines occur in the Prangat beds which show traces of gas but none of oil.

West of the Tenggarong anticline the intensity of the folding decreases considerably, so that a broad, flat syncline is formed between the Tenggarong and Seboeloe anticlines.

Indications of Oil.—The presence of oil in the Koetei district is suggested not only by the geologic structure of the region but by the occurrence of numerous oil seepages, gas seepages, and mud volcanoes. On Sanga Sanga River the presence of oil was first suggested by gas bubbles rising and bursting at the surface of the river. The mud of the river-banks was impregnated with heavy oil, and the basin of the stream was covered with a crust of asphalt. Five hundred yards to the southwest, in the hills, a burning seepage of natural gas occurred in former times.

Numerous oil seepages, outcrops of oil-bearing sandstone of the Sanga Sanga stage, and gas emanations occur along the crest of the Sanga Sanga anticline. On the flanks of the anticline smaller shows of oil occur, originating in the Moeara Djawa beds. Two small oil seeps occurring along Soengei Tiram and Soengei Senipah originate in the Kembang beds.

The dome on the Pelarang anticline near Mahakkam River shows oil seepages which issue from the Sanga Sanga beds. Four seepages noted on Soengei Sakakanan, north of Balikpapan, occur on the Pelarang anticline. These originate in the Sanga Sanga beds.

In the region between Samarinda and Tenggarong, which is marked by a series of steep and eroded anticlines, only a few insignificant oil and gas seeps and a few mud volcanoes occur.

Concessions.—The concessions range in size from 8,670 to

334,085 acres and most of them have been granted for periods of 75 years, in consideration of an annual royalty of $.201 per cubic meter of petroleum, coal, or other hydrocarbons produced. Usually a minimum yearly royalty is stipulated, ranging from $1,000 to $7,612.

Production.—The production of crude oil in metric tons in Koetei by the Royal Dutch-Shell group, 1910–1920, is illustrated by the following table:

TABLE II.

	Louise Concession.	Nonny Concession.	Moeara Concession.	Total.
1910.....	373,086	1,180	32,087	406,670[10]
1911.....	495,124	53,396	28,284	576,804
1912.....	370,278	53,852	26,715	450,845
1913.....	394,339	69,131	77,595	541,083[11]
1914.....	417,410	120,240	74,854	612,504
1915.....	419,053	164,288	68,150	651,491
1916.....	461,923	198,199	63,944	724,066
1917.....	398,841	152,559	65,901	617,301
1918.....	419,423	169,243	76,815	685,481
1919.....	.....[14]	.....[14]	.....[14]	770,000[12]
1920.....	.....[14]	.....[14]	.....[14]	744,119[13]

In addition to the output of the Royal Dutch companies the Nederlandsche Koloniale Maatschappij, a Standard Oil subsidiary, produced 188 metric tons in 1914; 217 tons in 1915; 371 tons in 1916; 139 tons in 1917 and 252 tons in 1918. No figures for later years are available. The production of the Koloniale Maatschappij came almost entirely from its Sadjau Concession.

Character of Oil.—Three types of oil were won in the Sanga Sanga oil field, from a single structure, such as the Sanga Sanga dome or the Sambodja dome, a heavy asphalt-base petroleum, a light asphalt-base oil, and a "paraffine oil." The specific gravity of the heavy oil ranges between 0.96 and 0.89; that of the light

[9] Jaarboek van het Mijnwezen in Ned. Oost-Indië, Batavia.

[10] Includes 317 metric tons produced on the Mathilde Concession.

[11] Includes 13 metric tons produced on the Toenkoedasing Concession and 10 metric tons produced on the Mintoet Concession.

[12] Estimated.

[13] Hoofd van het Mijnwezen, Batavia.

[14] No data.

oil between 0.88 and 0.85; and that of the paraffine oil between 0.86 and 0.84. These oils are from definite horizons in the Sanga Sanga beds. In a vertical section taken along the anticlinal axis, the heavy asphaltic oil horizons are found to occur in general at depths of 30 to 150 meters (98 to 490 feet) below sea-level; the light asphaltic oils generally between 240 and 300 meters (between 790 and 1,080 feet) below sea-level; and the light paraffine oil horizons for the most part between 330 and 385 meters (1,080 and 1,260 feet) below sea-level, although horizons of this oil have been found as low as 512 meters (1,680 feet) below sea-level. The mouths of the wells occur at altitudes varying from sea-level to 60 meters (196 feet) above sea-level.

The heavy asphalt-base oil has an average specific gravity of 0.9630. The boiling point ranges between 194° and 212° C. The kerosene fraction averages 35.5 per cent., and the lubricating oil fraction 50 per cent. The fraction over 300° C. gives an average of 26.5 per cent. of thick fluid paraffine, indicating an average paraffine percentage of 13.17 in the crude oil. The sulphur content of the crude oil varies between 0.101 and 0.159 per cent.

The specific gravity of the light asphaltic-oil averages 0.8688. This oil has a lower boiling point than the heavy asphaltic oil, varying between 61° and 78° C. The average yield of benzine and light oils is 25 per cent.; of kerosene is 49 per cent.; and of lubricating oils is 20.25 per cent. The sulphur content averages 0.11 per cent. The distillate over 300° C. contains on an average 35.5 per cent. of thick fluid paraffine, indicating an average paraffine content of 7.5 per cent. in the crude petroleum.

The average specific gravity of the light paraffine oil is about 0.8564. Its boiling point ranges between 55° and 84° C. The benzine fraction averages 22.6 per cent.; the kerosene fraction 46.5 per cent.; and the lubricating oil fraction 25 per cent. The distillate over 300° C. contains 40 per cent. of solid paraffine, indicating a paraffine content of 10.1 per cent. in the crude oil. The sulphur content averages 0.07 per cent.

In Table III. the analyses[15] typify the three groups of heavy asphaltic oil (I.), light asphaltic oil (II.), and light paraffine oil (III.) from Sanga Sanga.

TABLE III.

	I.		II.		III.	
	%	Spec. Gr.	%	Spec. Gr.	%	Spec. Gr.
Up to 150° C.....	2.4	0.804	17.5	0.815	33.05	0.7957
150° to 300° C.....	33.8	0.896	78.1	0.872	44.05	0.8426
Over 300° C.....	63.8	0.994	4.4	0.980	18.55	Solid distillate
Loss.....	....	....	....	....	4.35	.....

The oil-bearing horizons of the Sambodja field have been re-divided into four groups of horizons, according to the character of the oil they produce. These oils are named respectively the kerosene-asphalt oil; the residuum-asphalt oil; the asphalt-base kerosene oil; and the paraffine-base kerosene oil.

TABLE IV.

ANALYSES OF TYPICAL CRUDE OILS FROM SAMBODJA, EAST BORNEO.[16]

	Number of Analyses.	Fractions.		
		0°–150° C. Per Cent.	150°–300° C. Per Cent.	Over 300° C. Per Cent.
Kerosene-asphalt oils				
Horizon A 1.....	5	6.5	58.5	35
Horizon A 2.....	1	1.5	43.5	55
Residuum-asphalt oils				
Horizons B 1 and B 2.....	3	....	23	77
Asphalt-base kerosene oils				
Horizon C 1.....	15	26.5	49	24.5
Horizon C 2.....	5	22.5	53	24.5
Horizon C 3.....	1	26	41.5	32.5
Horizons C 4 and C 5.....	4	26.5	54	19.5
Horizons C 6 and C 7.....	10	25.5	53.5	21
Paraffine-base-kerosene oils				
Horizons D 1 and D 2.....	10	17.5	55	27.5
Horizons D 3, D 4 and D 5.....	24	20	50	30
Horizon D 5.....	1	16	51	33

[15] Analyses by James Kewey, The Crude Oils of Borneo.

[16] Escher.

Transportation and Refining.—For many years the oil of the Sanga Sanga and Moeara fields was transferred by tank-boats down Mahakkam River by sea to the refinery at Balikpapan. Now a pipe line through the tropical jungle carries the oil directly to Balikpapan. This refinery is said to be the largest in the world, but exact data as to its capacity are not available.

The Tarakan District.

Location and Extent.—The Tarakan district lies in the extreme northeast corner of Dutch Borneo, extending across the boundary line into British North Borneo. It includes principally the islands of Tarakan and Sebetik and portions of the immediately adjoining mainland. (Fig. 36.)

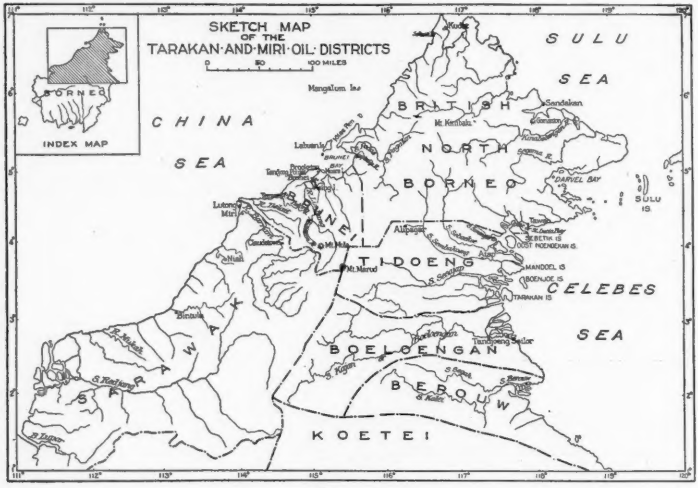

FIG. 36.

Physiography.—From Tandjoeng Seilor to the northwest end of Cowie Bay the coastal region of Boeloengan and Tidoeng consists, save for a few isolated hills, of mangrove swamps. The same is true of the banks of the larger rivers for a considerable distance inland. Inland from the coastal and riparian marshes the country is rolling and hilly.

Areal Geology.—The areal geology of northeastern Dutch Borneo has not been thoroughly worked out. Geologic investigations have been made of the coastal region from Kaniongan (or Mangkalihat) Peninsula up to Soengei-Boeloengan (or Kajan). North of Soengei-Boeloengan only reconnaissances have been made of the coastal region, which is 20 to 40 miles wide, and practically nothing is known of the interior.

Quaternary alluvium forms the coastal marshes of Tidoeng in an almost unbroken zone from Tandjoeng Seilor to the British boundary. It also occurs along Sembakoeng River as far as Atap and on the inside bends of the meanders.

Except in the narrow fringes where Quaternary coastal swamp occurs, Upper Tertiary sediments are shown in the larger coastal islands, as Tarakan, Boenjoe, Oost Noenoekan, and Sebetik. The narrow Quaternary, coastal, alluvial deposits are succeeded by a zone, 7 or 8 miles wide, of steep hills which are composed of Upper Tertiary beds.

The Upper Tertiary zone is succeeded to the west by a zone, 5 to 10 miles wide, underlain by the Upper Eocene. A broader zone (15 to 22 miles) of the Lower Eocene occurs to the west. The Sembakoeng beds (Cretaceous?) form a zone 30 to 32 miles wide chiefly in the upper valley of the river of that name. This zone bears generally north-northwest-south-southeast parallel to the upper source of Sembakoeng River. Beds of the lower stage of the Eocene recur, beyond the Sembakoeng beds, near Alipagar.

Stratigraphy.—The oldest sediments observed in Tidoeng are the Sembakoeng beds, which from their petrographic similarity to the Alino and Waringin beds (Middle Cretaceous) and from their stratigraphic position below the Eocene, are considered to be Cretaceous or at least pre-Tertiary. The Sembakoeng beds consist of very hard, silicified, dark-colored shales, alternating in many cases with equally hard silicified sandstone and conglomerate beds. Through the whole formation run bands colored red by *Radiolaria.*

The formations which overlie the Sembakoeng beds conform-

ably have been provisionally referred to the Eocene upon the basis of the presence of nummulites. The lower stage of the supposed Eocene consists of dark-colored clay-marls which alternate with hard sandstones. The clay content of the marls is somewhat low; this stage apparently forms the transition from the Sembakoeng shales to the upper marls. The upper stage is composed of soft gray-green to gray clay-marls, which are in many cases concretionary, fracturing in nodules. The bedding of the marls can be definitely determined only where the marls alternate with sandstone beds.

The Upper Tertiary of Tidoeng has not been subdivided. It consists principally of light-colored loose or poorly consolidated sands alternating with well-bedded conglomerates, white to light-yellow in color. Thin coal-seams occur here and there through the complex. The bedding is generally indistinct. In many places it can be distinguished only by the occurrence of the conglomerate strata or coal-seams, or by the occurrence of bands of clay or bituminous layers.

Quaternary alluvium overlies the Upper Tertiary beds unconformably.

Geologic Structure.—The coastal region of Tidoeng is in general gently folded. The axes of folding bear generally N. 30° W. The anticlines are represented by the islands, while the synclinal basins are occupied by broad estuaries and sea-straits between the islands and the mainland.

Five anticlines, whose axes trend in a northwestward direction, have been observed in the Tarakan district. The first or Tarakan anticline crosses Tarakan Island from southeast to northwest and may be followed across the British-Dutch frontier. A second anticline, parallel to the first, crosses Boenjoe and Mandoel Islands to the mainland and extends to the international boundary. The Poeloe Oost Noenoekan anticline, crossing the island of that name, and the two anticlines of Poeloe Sebetik, follow the same direction.

These anticlines are separated by corresponding synclines. The first of these is marked by the strait between Tarakan Island and

the mainland. The second is occupied by the central mouth of Soengei Sesajap and the strait between the islands of Boenjoe and Tarakan. The third is occupied by the mouth of the Simengaris and the strait between East and West Noenoekan. The fourth is occupied by the strait between Sebetik and Oost Noenoekan. The last is filled by Cowie Bay between Sebetik and the mainland near Tawao.

The principal anticline of the Tarakan district, that of Tarakan Island, consists mainly of two domes, separated by a structural depression. The axis of the anticline bears north and south.

Development.—The British Borneo and Burma Petroleum Syndicate made an unsuccessful attempt to drill at Tawao, British North Borneo, on the mainland opposite Sebetik Island. No details regarding this venture are known.

The Royal Dutch Co., by arrangement with the British Borneo Petroleum Syndicate, drilled a well on Sebetik Island in 1914. In July of that year the well had reached a depth of 1,437 feet and traces of oil were found. The outbreak of the war caused the suspension of operations. As only small shows of oil were met, the well was finally abandoned.

The Bataafsche Petroleum Maatschappij began development of Tarakan Island in 1905. Commercial production began in 1907 with an output of 16,432 metric tons.

Production.—The production of crude petroleum on Tarakan Island is illustrated by Table V. (p. 338).

Character of Oil.—The crude oils of Tarakan are comparatively uniform in character and show little variation with depth. They are all of asphalt base, with a specific gravity ranging from 0.942 to 0.955. They contain no benzine fractions and have a flash-point in the vicinity of 100° C. Their viscosity is low; they are quite liquid at 10° C. They contain only 0.6 per cent. of asphalt insoluble in alcohol ether, and have a coking value of 4 per cent. The sulphur content is 0.3 per cent. They are excellent liquid fuels and are used almost entirely for this purpose. They are also used successfully in Diesel engines and can be distilled for lubricating oils.

TABLE V.

PRODUCTION OF CRUDE PETROLEUM ON TARAKAN ISLAND, 1910–1920, IN METRIC TONS.[17]

	Tarakan I.	Tarakan II.	Tarakan East.	Tarakan North.	Total.
1910....	2,327	224,475	....	...	226,802
1911....	2,954	234,925	....	...	237,879
1912....	2,613	218,979	....	...	221,592
1913....	3,157	221,004	1,318	...	225,479
1914....	41,891	206,864	4,965	306	254,026
1915....	89,165	147,560	5,418	40	242,183
1916....	97,791	132,484	2,684	...	232,954
1917....	117,060	133,517	1,245	...	251,822
1918....	185,757	146,758	366	812	333,693
1919....	.....[20]	.....[20]	....[20]	...[20]	600,000[18]
1920....	.....[20]	.....[20]	....[20]	...[20]	711,609[19]

Wells.—The Tarakan oil fields in 1920 contained about 300 derricks. The wells had an average specific capacity of about 100 metric tons per day by pumping. One well flowed about 500 tons a day; and another of equal capacity had become choked with sand; it was expected, however, to come in again flowing. New wells were being drilled.

Transportation and Refining.—The oil is pumped from the fields to Linkas, the port of embarkation, where there is a storage plant of 15 tanks of 20,000 barrels capacity. Two more of a capacity of 50,000 barrels were under construction in 1920. The tanks are located about 60 feet above sea-level and the oil is loaded by gravity through two 8-inch pipe lines. It is claimed that a ship may be loaded at the rate of 400 tons per hour.

For refining, the Tarakan oil is shipped in tank steamers to Balikpapan. Much of it, however, is exported directly as fuel oil, no refining being necessary. Exports of fuel oil from the customs district of Tandjoeng Seilor amounted to 101,204 cubic meters (636,573 barrels) in 1913; 154,266 cubic meters (970,335 barrels) in 1914; 183,695 cubic meters (1,155,440 barrels) in

[17] Jaarboek van het Mijnwezen in Ned. Oost-Indië, Batavia.

[18] *Financial Times*, London, January 19, 1920.

[19] Hoofd van het Mijnwezen, Batavia.

[20] No data.

1915; 185,518 cubic meters (1,166,910 barrels) in 1916; 188,890 cubic meters (1,188,157 barrels) in 1917; 172,200 cubic meters (1,083,139 barrels) in 1918; and 529,379 cubic meters (3,329,794 barrels) in 1919.

The British Borneo Oil District.

Location and Extent.—This district includes all the possible oil-bearing territory of the British portion of Borneo, except the north end of Sebetik Island and the immediate surroundings of Cowie Bay, which have been discussed under the Tarakan district. The entire zone of folded Tertiary sediments of the British portions of Borneo may be petroliferous, but the present producing district is a relatively small part of the zone. The folded Tertiary zone includes the coastal region of northern Sarawak, the coastal Tertiary zone of Brunei and the coastal region of British North Borneo northwestward to Cape Sampanmangio and southward almost to the Dutch frontier. The only portion, however, of this zone of which the geologic structure is known with any certainty or detail is the comparatively small area which surrounds Brunei Bay.

The Miri oil field is at present the only producing field in the British portion of Borneo. It is situated on the west coast of Borneo in the Rajahship of Sarawak, along the Brunei frontier. Among other possible oil fields are the Belait district of northwestern Brunei, adjacent to the Miri field; the island of Labuan; the Klias Peninsula; and the valley of Sekuati River, in British North Borneo.

Physiography.—British Borneo as a whole may be divided into three physiographic provinces, (1) a central mountain chain, (2) a zone of low hills, and (3) a zone of coastal swamps.

The mountain chain which forms the boundary between British and Dutch Borneo extends from Cape Datu (or Datoe) eastward to about longitude 113° E., thence in a generally northeastward direction to the sea. The mountain chain is quite irregular in elevation, and contains the highest peak in the island of Borneo, Mt. Kinibalu, 13,698 feet in altitude. The central range

varies from 6,000 to 8,000 feet in elevation, while the ranges which form the boundary between Sarawak and West Borneo are only 2,000 to 3,000 feet in height. This boundary range extends parallel to the northwest coast of the island at an average distance of 100 miles from the sea.

The hill zone comprises the greater part of British Borneo. It consists of hills averaging 500 feet in elevation. The coastal swamps of British Borneo, in contrast with those of the Dutch portion of the island, are small in extent and mangrove swamps are largely limited to the coast of Brunei Bay.

Areal Geology.—The mountains which form the boundary between the British and Dutch possessions in Borneo consist of granite, diabase, serpentine, and gneissic rocks, and of hard Paleozoic sandstones, quartzites, slates, and massive blue Carboniferous (?) limestones and extends in a generally southwest-northeast direction. Certain peaks, notably Marud and Kinibalu, are composed of granite. The flanking ranges consist largely of Paleozoic sediments. Paleozoic quartzitic sandstones occur on Kapinaga River within 10 miles of Brunei Bay, and along Padas River. Mt. Mulu in Brunei is largely composed of Carboniferous (?) limestone.

The coastal part of the hill region is Tertiary. East of Padas Bay, a small indentation at the northeast corner of Brunei Bay, the Tertiary is only 10 to 15 miles in width. At the town of Brunei it is about 40 miles wide; and further southward in the valley of Barram River, in northern Sarawak, it is about 80 miles wide.

A belt of Quaternary alluvium averaging about 60 kilometers (36 miles) in width extends along the coast of southern and central Sarawak, narrowing until it disappears at Brunei Bay.

Stratigraphy.—The Tertiary, which is the oil-bearing system of British Borneo, is composed in general of sandstones, shales, marls, conglomerates, and limestones, with interbedded lignite seams. The majority of observers have correlated these strata with the Lower Tertiary of the south of Borneo and especially

with Verbeek's "alpha" and "beta" stages of the Eocene. Later Tertiary, however, in all probability occurs.

A limestone formation occurring along Madalam River between the provinces of Brunei and Sarawak has been identified by its fossils as Eocene. The lignite measures of Brunei and Labuan, which consist of alternating beds of clay, sandstone, and conglomerate, with several good lignite seams, are considered by Evans to be Eocene.

The coal measures of Labuan, as exposed at Kubong Bluff at the northern extremity of the island, consist of a base of blue shale probably 150 to 180 feet thick, which includes extremely thin layers of argillaceous sandstone, and is overlain by alternating sandstones, conglomerates, clays, and coal seams to a total thickness of over 300 feet. The sandstones vary in color from red and blue to white, and in texture from coarse to fine. The conglomerates are composed of quartz, sandstone and coal pebbles, cemented generally by oxide of iron. The clays are generally blue, and in many cases contain nodules of iron oxide. Fireclay underlies the coal seams. The coals are lignitic, containing 6.1 per cent. of hygroscopic water, and include masses of semi-transparent resin.

Coal measures of supposed Eocene age occur along the coast of northern Sarawak, Brunei, and British North Borneo. Some of the best-known occurrences are those of River Linga, a tributary on the left bank of Batang[21] Lupar; at the junction of Simunjan and Sadong rivers; along Redjang and Mukah rivers; at Muara Island, opposite Brooketon, and Gaya; on Marudu and Sandakan bays; and on Kinabatangan River. On Sekuati River Hatton found a resinous coal similar to that of Labuan Island.

It is uncertain whether all the coal and lignite seams of British Borneo are Eocene. Some indeed may be of later Tertiary age. The succession of Tertiary rocks has not been worked out with the same degree of precision in British Borneo as in Dutch Borneo. Miocene coal-measures are extensive in Dutch Borneo, as

[21] *Batang* in Malay means "river."

well as in Sumatra, and like the coal measures of British Borneo have proved to be petroliferous.

The Oligocene is represented by bluish-gray clays, and by shales and marls. Orbitoid limestones of supposed Miocene age have been found on Madalam River, and on Gomanton Hill near Kinabatangan River in the northeast part of the island. Nummulitic limestones, whitish or bluish in color, occur at the coastward edge of the hill zone of central Sarawak.

The lower Quaternary sediments consist of conglomerates of quartz-pebbles or of pebbles of Tertiary rocks, chiefly sandstones and coral limestone, in places interspersed in a clayey earth, or cemented in other places by a hard siliceous cement. The upper beds are composed of a somewhat sandy clay, which becomes less sandy toward the top.

Late Tertiary volcanic activity is evidenced in the south of British North Borneo by hills of basalt and feldspathic and pyroxene andesites, notably on the north of Cowie Harbor. The extent of the Cowie Harbor volcanic region is unknown, but it may embrace the Darvel Bay region.

Intrusive and extrusive igneous rocks occur locally throughout western Sarawak. The intrusives, particularly quartz-porphyry dikes, have penetrated and disturbed the coal measures of the Bau and Bidi gold district in Upper Sarawak subsequent to the Miocene folding. In central Sarawak igneous rocks, particularly basalts, hornblende-augite-andesites and feldspar porphyries, have also disturbed the coal measures and occur as hills and peaks. These intrusions are accompanied by deposits of tuffs and volcanic agglomerates.

Structure.—The Tertiary of the Brunei Bay region and of northern Sarawak is strongly folded. The axes of folding bend considerably in their courses but trend in general in a south-southwest to north-northeast direction, parallel to the coast.

Three anticlines have been determined at Brunei. The westernmost of the three a comparatively closed fold, is exposed on the steep cliffs of Tandjong[22] Puniet. On its eastern flank the beds

[22] *Tandjong* or *tandjoeng* in Malay means "cape."

strike N. 45° W. and dip 30° to 50° to the east; on the western flank the strike is N. 10° E. and the dip 20° to 50° to the west. The remaining two anticlines occur between Asing Island and the town of Brunei. Their axes bear to the northeast, with strata dipping 50° to 80° on both sides. The Eocene (?) coal measures of Brooketon are exposed in both these anticlines.

The characteristic course of these folds is sinuous. The anticline of Tandjong Puniet may be connected with the southern of the two anticlines of Labuan Island. The two anticlines between Asing Island and Brunei reappear on the Klias Peninsula. The northward continuation of these two anticlines appears to be interrupted by a normal fault. The three parallel folds on the northern end of Klias Peninsula are probably the northeastward continuation, beyond the fault, of the southern folds.

The possibilities of obtaining petroleum in commercial quantities from the Brunei Bay region are, in the judgment of Schmidt, not especially favorable. The anticlines occur with steeply dipping limbs; only the southern anticline of Labuan and the central anticline of the northern Klias Peninsula have a broad crest with flat-lying strata. The nearness of the Paleozoic central mountain region postulates this strong folding of the strata, and where the Tertiary foreland farther to the south is broader, less close folds may be expected.

The geologic structure of the Miri field proper is not so well known as that of Brunei Bay. There is, according to Kewley, a well marked anticline, of which the eastern limb is the steeper. The oil is drawn from the western limb.

The Quaternary beds of the coastal plain are generally horizontal or only slightly inclined as at the border of the Tertiary hill-land.

Indications of Oil.—Oil seepages, issues of natural gas, and mud volcanoes are situated along the axes of the anticlinal folds, on Klias Peninsula and on Labuan Island. Oil seepages further occur along the anticlinal axes on Brunei Peninsula. A new island, which owed its origin to an eruption of natural gas, appeared

off the Klias Peninsula, opposite Labuan Island, on September 21, 1897.

On Labuan Island a thick black oil seeps from a sandstone, 7 meters (23 feet) thick, which is intercalated in shales. A bore hole drilled 450 feet into this formation encountered at 391 feet a high-pressure flow of gas, but no oil. At Kubong Bluff a shaft sunk 20 feet delivered in 1879 about 12 gallons daily of petroleum of 0.965 specific gravity.

Petroleum seepages have been discovered in British North Borneo on River Sekuati. Not far from the coast the clayey soil of a tidal swamp is saturated with petroleum. A shaft sunk to a depth of 35 feet revealed beneath 4 feet of surface clay an oil-bearing ferruginous sandstone inter-bedded with shales. Pieces of coal with resinous inclusions were also found. The petroleum is a thick oil or bitumen, containing a paraffine oil and an oxidizable body belonging to the camphors or turpentine.

The oil of the Miri field occurs in a sandstone formation. The strata are of Miocene age, according to Kewley, and coals, which mark the Miocene elsewhere in Borneo, are absent.

Development.—The Anglo-Saxon Petroleum Co., a Royal Dutch-Shell subsidiary, began drilling in the Miri field of Sarawak in 1911. Several wells came in at a shallow depth, below which a second oil stratum was struck. Commercial production began in 1912. The British-North Borneo and Burma Petroleum Syndicate made unsuccessful attempts at drilling along Kinabatangan River. No details are known about this venture.

An arrangement was made by the British-North Borneo and Burma Syndicate in 1912 with the Nederlandsche Koloniale Petroleum Maatschappij, a Standard Oil subsidiary, under which the Koloniale Mij. was to prospect the entire British-North Borneo concession and develop the Klias Peninsula. A similar arrangement was made in 1914 for the Brunei concessions. Four wells were sunk by the Nederlandsche Koloniale Petroleum Mij. for the British-Borneo Petroleum Syndicate on Klias Peninsula; small shows of oil and gas were struck in Nos. 1 and 2, but these were abandoned at 1,500 and 1,280 feet respectively. According

to the profile drawn by Schmidt, these wells were located in a close syncline. Well No. 4 struck oil at 2,303 feet and produced at the rate of 1,200 gallons of light oil a day, but the well was capped. After the conclusion of the agreement with the Nederlandsche Koloniale Petroleum Mij., the D'Arcy Exploration Co., which took over the lease, did not attempt to continue drilling on the Klias Peninsula.

On the Mangalum Island, Well No. 1, drilled by the Nederlandsche Kolonial Petroleum Mij. for the British-North Borneo Petroleum Syndicate, reached in 1916 a depth of 1,268 feet and Well No. 2 a depth of 1,030 feet.

In western Brunei, the oil leases at Rempayoh in the Belait district were worked in 1915 by the Nederlandsche Koloniale Petroleum Maatschappij, by arrangement with the lessees, the British-Borneo Petroleum Syndicate. Well No. 2, in which oil had been found in 1914 at a depth of 1,820 feet, continued to produce at the rate of 4 tons a day. As no storage was available, no reliable estimate of the well's yield could be made. The well was pumped intermittently for a few days at a time in the daytime only. The yield continued until June, 1916, when it amounted to 1,500 gallons per day. As at that date, the oil was no longer required for fuel and there was not storage for it, the pump was withdrawn and a lead pipe connected to allow the gas and oil to escape.

Well No. 4 had reached a depth of 2,132 feet by February 19, 1916. Operations were finally suspended on April 5, 1916, because of difficulties with the casing. Work was finally abandoned by the Nederlandsche Koloniale Petroleum Mij. in August, 1916. An agreement was made in 1918 with the D'Arcy Exploration Co., Ltd., for a further examination of the Belait field. Exploratory work was conducted in 1919 by the geologists of the D'Arcy Co., but the results have not been published.

In the East Tutong field, Temuan district, the Anglo-Saxon Petroleum Co. drilled a test well in 1915 at Paya Minuman, near Kampong Ikas, about 5 miles from Lubok Tibangun on Temuan River. The first well was abandoned in 1917 and a second well

was drilled at Sembatang on Tutong River. Well No. 2 was sunk to a depth of more than 2,500 feet. Slight shows of oil and gas were met, but no substantial results were obtained. Operations were suspended in 1919.

The Shanghai-Langkat Co. drilled at Jerudong, but difficulties with sliding formations caused the abandonment of the lease in 1915. A prospecting license to a field lying 25 miles west of Tutong River was obtained. Drilling commenced late in 1916, but was abandoned early in 1917.

Production.—Commercial production of petroleum in British Borneo began in 1912 in the Miri field of Sarawak. The development of the industry is shown by the following statistics:

PRODUCTION OF CRUDE PETROLEUM IN SARAWAK, 1912–1920.

	Metric Tons.[23]		Metric Tons.[23]
1912	5,534	1917	77,604
1913	30,562	1918	72,511
1914	65,185	1919	85,695
1915	67,000	1920	146,729
1916	90,067		

Character of Oil.—The crude oil of Miri is a thin fluid oil, brown in color, and translucent. Its specific gravity ranges from 0.890 to 0.925, and its viscosity (Redwood II.) at 10° C. is 45 seconds. It yields about 20 per cent. of a benzine low in volatile fractions, about 30 per cent. of kerosene, and a residue of thin oil of a low cold-test. Of the kerosene fraction 25 per cent. is absorbable in 100 per cent. sulphuric acid. The crude oil contains 0.4 per cent. of sulphur and no asphalt insoluble in alcoholic ether.

The benzine fraction was found, on analysis, to contain 80 per cent. of naphthenes, 15 per cent. of paraffines, 0.4 per cent. of benzine, 1.9 per cent. of toluene, 1.5 per cent. of xylenes, and 1.0 per cent. of high aromatics.

A dark-brown petroleum from Sarawak, with a specific gravity of 0.924, reported by Redwood, yielded on analysis 94.3 per cent.

[23] Annual reports, Royal Dutch Co.

of lubricating oil, and 3.3 per cent. of coke. A heavy oil from Labuan, with a specific gravity of 0.965 at 76° F., gave 97.1 per cent. of lubricating oil and 2.6 per cent. of coke.

Transportation and Refining.—The crude oil from the wells at Miri is delivered by a pipe line to Lutong, where a refinery on the Trumble system was built in 1917 and 1918. It began operations in 1919. Two 8-inch submarine pipe lines from the refinery permit the rapid loading of steamers.

Prior to the building of the Lutong refinery, a part of the crude petroleum from Miri was shipped to Sumatra to be refined. Statistics of these shipments, from official Dutch sources, follow:

IMPORTS OF CRUDE PETROLEUM FROM SARAWAK INTO THE DUTCH EAST INDIES, 1913–1919.[24]

	Liters	Barrels
1913	.....	....
1914	7,079,056	44,528
1915	27,107,335	170,505
1916	12,222,962	76,882
1917	1,934,798	12,170
1918	2,801,160	17,619
1919	2,955,260	18,589

In 1914 and 1915 these shipments were landed at Palembang, Sumatra, to be distilled at the Pladjoe refinery. A part of the 1916 shipments was sent to Pangkalan Brandan, East Coast of Sumatra, and Balikpapan. From 1917 to 1919 the Miri oil was refined at Pangkalan Brandan.

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[24] Statistiek van den Handel en de In-en Vitvoerrechten in Ned. Indië.

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THE GOLD–QUARTZ VEINS OF BRIDGE RIVER DISTRICT, B. C., AND THEIR RELATIONSHIP TO SIMILAR ORE–DEPOSITS IN THE WESTERN CORDILLERAS.[1]

W. S. McCann.

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INTRODUCTION.

The Bridge River district is situated one hundred miles north of Vancouver on the eastern margin of the Coast Mountains of British Columbia, and is about one hundred and forty miles inland from the Pacific coast. The gold-quartz deposits of the district bear a striking resemblance both in mineralization and geological associations to those of southeastern Alaska to the north, and Grass Valley, California, to the south; and this resemblance is suggestive of a common origin. The following paper describes

[1] Published with permission of the Director of the Geological Survey of Canada.

briefly the gold-quartz deposits of the region, and their resemblance to the ore deposits of the above-noted districts.

The writer wishes to express his indebtedness to Professors Alan M. Bateman, Adolph Knopf, and Charles Schuchert, of Yale University, for assistance in preparing the dissertation of which this is a part.

GENERAL GEOLOGY.

Bridge River District.—The rock formations of the Bridge River district range in age from Pennsylvanian to Recent. The oldest, or Bridge River series, are composed of highly metamorphosed sedimentary and contemporaneous volcanic rocks correlated with the Cache Creek series[2] in the region east of the Bridge River district, and determined by Dawson, because of the fossil *Fusilina,* to be of Carboniferous (Pennsylvanian) age. These rocks form the core of an anticline pitching gently to the northwest, and which is flanked on either side by the remnants of two Mesozoic series, the Cadwallader (Upper Triassic) and Eldorado (Lower Cretaceous) series respectively.

Lying between the Palæozoic and Mesozoic series are remnants of serpentine volcanic rocks which covered the Palæozoic erosion surface to a great extent. They are believed to be of Lower Triassic age.

Plutonic rocks of the Coast Mountains batholith, having the composition of quartz diorite and granodiorite, and their corresponding dikes, intrude the Palæozoic and Mesozoic rocks; whereas stocks and dikes of augite diorite, with which the gold-quartz veins are associated, cut only the rocks which are older than Lower Cretaceous. The augite diorite is considered to be older than the granodiorite batholith because of the difference in degree of metamorphism, the augite diorite being quite schistose in places, and strongly fractured; whereas the quartz diorite is non-metamorphosed and lacks the presence of large fissures and quartz veins. The augite diorite, because of its being older and more basic than batholithic rocks, is believed to have been a marginal

[2] Dawson, G. M., Ann. Rep. Geol. Surv. Can., Vol. VII., 1894, Pt. B.

differentiate, and a forerunner of considerable advance, of the Coast Mountains batholith.

A small area of volcanic rocks, chiefly of andesitic composition with which are associated contemporaneous sedimentary rocks containing unimportant seams of lignite, occurs within the district. These rocks are referred provisionally to the early Tertiary. Unconsolidated deposits of glacial till, gravel, and sand, of Glacial and post-Glacial age cover the bottoms and sides of the valleys in many places; but the most recent of all deposits is a thin bed of volcanic ash which overlies even the most recent river gravels and forms a pulverulent mantle to the ground for large areas.

Similarity of South-eastern Alaska and Southern California with the Bridge River District.—In his report on the Juneau Gold Belt of South-eastern Alaska Spencer[3] describes a zone of greatly altered Lower Carboniferous rocks regarding which he states:

> These rocks comprise marble, schist and phyllite, intruded by various igneous masses and locally overlain with evident unconformity by moderately metamorphosed representatives of the Mesozoic strata and also by slightly disturbed Tertiary strata carrying seams of coal.

The Mesozoic strata referred to above are composed of conglomerates, greywackes, and slates, which on palæontological evidence compare in age with the Upper Jurassic, Mariposa beds of California;[4] and the older rocks correspond with those of the Calaveras formation in that region.[5]

Though the geological relationships between the sedimentary formations of the three regions are of striking similarity, yet the correlation of the igneous rocks and their auriferous quartz veins is difficult. In the Bridge River district there is evidence of the augite diorite having been involved in the folding of the Upper Triassic rocks, which probably were disturbed at the close of the Jurassic. This intrusion, therefore, is correlated with that of

[3] Spencer, A. C., Bull. U. S. G. S. 287, 1906, p. 10.

[4] Lindgren, Waldemar, "The Gold-quartz Veins of Nevada City and Grass Valley, Cal.," 17th Ann. Rep. U. S. G. S., Pt. II., p. 98.

[5] *Idem.*, p. 79.

the granodiorite at Grass Valley, California,[6] and is believed to have occurred before the intrusion of the gold-bringing diorite of Middle Cretaceous age,[7] of south-eastern Alaska.

The Tertiary rocks of Bridge River district and south-eastern Alaska are similar in that they contain some coal seams, whereas in southern California the Tertiary is represented by the product of volcanic activity and auriferous gravels.

The general geological relationships that exist between the formations of the three districts under discussion are illustrated in the following table.

TABLE I.

	California.[8]	Bridge River District, B.C.	South Eastern Alaska.[9]
Tertiary	Auriferous gravels Rhyolite tuffs	Volcanic and sedimentary rocks with unimportant coal seams	Basaltic surface flows, slightly disturbed strata carrying seams of coal
Middle Cretaceous		Granodiorite and quartz diorite (Coast Mountains batholith)	Diorite (Coast Mountains batholith) gold-quartz veins
Lower Cretaceous		Eldorado series	Conglomerates
Close of the Jurassic	Granodiorite batholith, diorite-peridotite gabbro group, gold-quartz veins	Gold-quartz veins albitite dikes augite diorite	
	Diabase and porphyrite	Cadwallader series (Upper Triassic)	
Triassic or Jurassic	Mariposa beds (late Jurassic)		Conglomerates, greywackes, and slates
Lower Carboniferous	Calaveras formation	Bridge River series	Marble, schist, phyllite

[6] Lindgren, Waldemar, *loc. cit.*, p. 104.
[7] Spencer, A. C., *loc. cit.*, p. 15. Wright, C. W., Bull. U. S. G. S. 287, p. 147.
[8] Lindgren, W., U. S. G. S. 17th Ann. Rep., Pt. II.
[9] Spencer, A. C., Bull. U. S. G. S. 287, pp. 13–19.

Composition and Structure of the Coast Mountains Batholith.—The outstanding event in the geological history of the Coast Mountains, and the most important from the economic point of view, was the latest-Jurassic mountain-making revolution, with the accompanying, but slightly deferred, batholithic invasion and consequent mineralization. These great intrusive bodies form the axis of the Coast Mountains and are indicated on the geological map of Canada as being from 30 to 75 miles wide and about 1,200 miles long.

The uniformity in composition of these plutonic rocks is striking. For the most part they are of granodiorite, and many, according to Daly,[10] either represent a less perfect differentiation of the same kind of syntectic (solution of one rock in another) as that from which the average post-Archean granite has been differentiated; or, a differentiation of a syntectic of primary basalt and the Pre-Cambrian granite terrane together, with a large amount of argillaceous sediments engulfed in the magma by the processes of magmatic stoping. Bowen,[11] however, disagrees with the idea of such rocks resulting from the assimilation of sediments by the magma, and shows how most, if not all, rocks could have been derived from a basaltic magma entirely by differentiation controlled by crystallization.

Locally these plutonic rocks vary in composition from that of granite to diorite and gabbro, due to processes of differentiation in the original magma during intrusion, and, in many cases, differences in composition are observed to be due to the separate intrusion of the many interlocking bodies that make up the great composite batholith.[12]

ECONOMIC GEOLOGY.

Development of Mining.—The gold-quartz veins of the Bridge River district are the most important ore-deposits known to exist

[10] Daly, R. A., "Geology North American Cordillera, 49th Parallel," Geol. Surv. Can. Memoir 38, p. 784–5.

[11] Bowen, H. L., *Jour. Geol.* Vol. 35, 1915. Supplement to No. 8, pp. 1–91.

[12] Spencer, A. C., *loc. cit.*, p. 14.

in the entire Lillooet Mining Division of British Columbia. No veins of proved economic value have been found outside the limits of the augite diorite bodies. Mining operations have therefore been mostly confined to a narrow belt in the vicinity of Cadwallader Creek, where the augite diorite stock has its greatest development.

The mining properties are still in the prospect stage except for a few small mines on Cadwallader Creek. Even in these no vein has been explored to a depth exceeding 300 feet. In the mills which have been operated no treatment other than that required for amalgamation of the gold has been practised, consequently there has been a heavy treatment-loss represented by the gold contained in the sulphides.

Abundant water power is available for mining operations, but hydraulic prospecting is difficult because of the thick mantle of glacial till (locally called "cement") which covers the surface. Mining activity has declined since the war and at present there is little work being done. A revival of activity is anticipated, however, in the near future.

Relationship of the Gold-quartz Deposits to the Intrusion of the Coast Mountains Batholith.—The importance of igneous intrusion with relation to the genesis of ore deposits is well known and the relation of certain types of deposits to particular geological epochs has been pointed out by Lindgren,[13] who has shown that gold-quartz veins of almost identical character occur from Lower California to Alaska associated with large-scale batholithic intrusions of quartz-monzonite or granodiorite of Mesozoic age. In a later paper,[14] the same author states that the great masses of these intrusives are unusually free from mineral deposits, while the margins of the batholiths yield abundant deposits, those of gold and copper being the most important.

Relationship of the Veins to Country Rock.—All the important gold-quartz veins that have been discovered up to the present time occur within the augite diorite, and this fact has led to the

[13] Lindgren, W., T. A. I. M. E., Vol. 33, 1902, p. 797.

[14] "Metallogenic Epochs," ECON. GEOL., Vol. IV., 1909, p. 419.

belief that the profitable veins are confined to this rock. Consequently little prospecting has been done outside the boundaries of the augite diorite, and little information is available for deciding the question. Where it has been possible to study the character of the intruded rocks at their contact with the intrusive rock, they are found to be schistose and relatively soft. In the Coronation mine a vein that crosses the contact into serpentine schist frays out and disappears within a few feet of the contact. It would appear then that the movement which caused the fissure in the augite diorite was absorbed in the serpentine by distortion and plastic flow. Similar phenomena have been recorded elsewhere,[15] and are not uncommon where rocks of inferior competency occur. The augite diorite, on the other hand, by virtue of its homogeneous and brittle character, has physically been favorable for the formation of fissures through fracturing. The fissuring has expressed itself in two systems normal to one another.

Not only are the veins probably confined to the augite diorite, but they are believed to have a direct genetic connection with its intrusion, as will be shown later.

Mineralogy of the Veins.—The table on page 357 shows the different minerals which have been noted in the veins of the Juneau Gold Belt, Bridge River district, and Grass Valley.

Gold occurs in the free state, and also intimately associated as a mechanical mixture with the sulphides, especially arsenopyrite. It is also closely associated with the tellurium minerals (probably sylvanite) and with stibnite and chalcopyrite. (See Fig. 37.) The principal gangue mineral is quartz, but calcite is of common occurrence.

Ore-Shoots and their Origin.—On account of the small amount of development work in the mines of the district, little information is available concerning the occurrence of ore-shoots. The upper parts of the veins which have been worked have been found to contain relatively more gold than parts at greater depths. This

[15] Lindgren, W., 17th Ann. Report U. S. G. S., Pt. II., p. 167. Irving, J. D., ECON. GEOL., Vol. 1, p. 48.

is probably due to residual enrichment through oxidation near the surface.

Juneau.	*Bridge River.*	*Grass Valley.*
Quartz	Quartz	Quartz
Rutile	Rutile	
Calcite	Calcite	Calcite
Dolomite	Ferro-dolomite	
Siderite	Siderite	
Albite		
Adularia		
Mica		
Sericite	Sericite	Sericite
Mariposite	Mariposite	Mariposite
Tourmaline		
		Chalcedony
		Magnesite
		Scheelite
Gold	Gold	Gold
Electrum		
Pyrite	Pyrite	Pyrite
Pyrrhotite	Pyrrhotite	Pyrrhotite
Chalcopyrite	Chalcopyrite	Chalcopyrite
Galena	Galena	Galena
Sphalerite	Sphalerite	Sphalerite
Arsenopyrite	Arsenopyrite	Arsenopyrite
Stibnite	Stibnite	
Tetrahedrite	Tetrahedrite	Tetrahedrite
Molybdenite		Molybdenite
Pyrargyrite		Pyrargyrite
Arsenic		
Magnetite		
	Tellurium minerals	Tellurium minerals
		Altaite
		Tetradymite
		Marcasite
		Cinnabar

At the lowest depths to which the workings extend, namely 300 feet below the surface, some rich ore-shoots have been found. In the King vein at the Lorne mine an ore-shoot occurred at the intersection with another vein. Similar cases were observed in the Coronation and Pioneer mines. It would appear, therefore, that the junctions of intersecting veins have afforded favorable

places for the precipitation of the gold and sulphides, either through the disturbing of the chemical equilibrium by mixture of solutions of slightly varying composition, or through the sudden

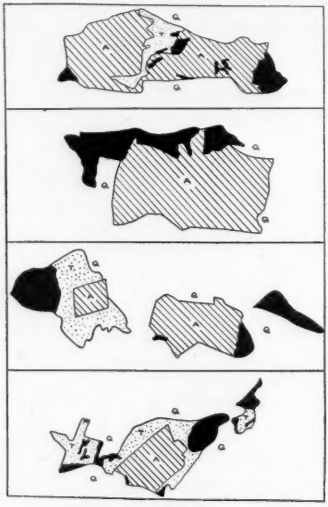

FIG. 37. Camera lucida drawings (× 20) of polished sections of ore from Bridge River District, showing the intergrowth of some of the metallic minerals. Black, gold; hatched, arsenopyrite; dotted, tellurium mineral; white, quartz.

decrease in velocity of the solutions in places where there was more room for circulation.

The latter reason would account for the occurrence of ore-shoots in the wider parts of the veins. Such deposits are usually near the walls rather than in the central parts of the veins, and are mostly composed of arsenopyrite with which the gold is intimately associated. Similar conditions are reported from the Allegheny district, Cal.[16]

The richest veins are those that have a ribboned structure, which has been produced by movement in the plane of the vein subsequent to deposition, resulting in the shearing of the quartz

[16] Ferguson, H. G., Bull. U. S. G. S., 580, p. 170.

into plates parallel to the walls. Lines of original sulphide deposition have been inherent lines of weakness, consequently in the movement the sulphides have been pulverized and drawn out and even slickensided, to have produced the ribboned appearance (see Plate IV*a*). Ribboned structure is a common characteristic of the veins at Grass Valley, Cal. In the Juneau Gold Belt definitely defined fissure veins are seldom found.

Tenor of the Ore.—Systematic assaying has never been done by the mine operators in the past. When rich assays have been reported there is no means of knowing whether they have been of rich specimens. In the Coronation mine a small shoot of spectacular ore was found. The Turnplate ledge of the Lorne mine assayed $250 per ton; and in the Pioneer mine a small ore-shoot is said to have yielded $60 per ton on the amalgamation plates after all the rich specimens had been removed. It is stated that the average extraction of gold by amalgamation from the ore of the King vein of the Lorne mine has been $17,[17] while the oxidized portions ran as high as $80 per ton. Samples collected by the writer from this vein assayed about $6.50 per ton.

The close association of the gold with the sulphides, particularly arsenopyrite, makes the actual gold content of ore greater than it would appear from treatment by amalgamation only. Concentrates from the Pioneer and Lorne mines have assayed from $100 to $300 per ton. Recently the concentrates have been saved at the Pioneer mine, but formerly the general practice in the district was to allow the sulphides to accompany the tailings from the arrastra beds and amalgamation plates. These tailings contain from $3 to $6 in gold per ton.

Metasomatic Processes.—The metasomatic processes to which the rocks adjoining the gold-quartz veins have been subjected through the agency of vein solutions may be best understood by comparing the physical and chemical character of the fresh augite diorite distant from the veins and the altered rock adjoining them.

The fresh rock is composed of hornblende, augite, andesine,

[17] Bateman, Alan M., Dissertation for the degree of Ph.D., Yale University Library, 1913, p. 437.

and small amounts of orthoclase and quartz, with chlorite, secondary hornblende, kaolin, zoisite, sericite, and calcite as alteration products. Apatite, ilmenite, and magnetite are present as accessory minerals. The hornblende usually is idiomorphic with respect to the plagioclase, and basal sections show cleavage parallel to the prismatic faces, showing that it is an original constituent of the rock and not paramorphic after augite. In other cases it occurs as an alteration product of augite.

The augite diorite adjacent to the quartz veins has been profoundly altered by metasomatic processes. The dark grey color of the fresh rock is lost and the altered rock has been bleached to a light grey to almost white, relatively soft, rock of a general characterless appearance. (Plate IV*b*.) There is also a marked development of iron sulphides in the wall rocks where the metasomatic action has been greatest.

Under the microscope the result of the alteration is the production of a finely felted aggregate of sericite, calcite, quartz, and ferrodolomite. The ferromagnesian silicates are first altered to chlorite before being finally changed into sericite. In places where the alteration has not been extreme, secondary albite is developed to a marked degree, sometimes making up 16 per cent. of the altered rock. The albite was probably made at the expense of the potash-bearing feldspar originally present in the augite diorite and in these sections it is clear and fresh compared to the plagioclase clouded with alteration products. (See Plate IV, *c, d*.)

The calculated mode of the altered augite diorite is as follows:

Albite	16.24
Sericite	31.98
Ferrodolomite	23.88
Quartz	21.54
Chlorite	3.88
Magnetite	1.23
	98.75

Albitization of the wall rocks has been noted elsewhere in deposits of a similar character, viz., at Juneau[18] and Eagle River,[19] in South-eastern Alaska.

[18] Spencer, A. C., U. S. Geol. Surv. Bull. 287, 1906, p. 111.
[19] Knopf, A., U. S. Geol. Surv. Bull. 502, 1912, pp. 36–40.

The chemical changes which have taken place are apparent from the comparison of the analyses of altered and unaltered rock in Table II., and Fig. 38.[20] In the latter the gains and losses of each

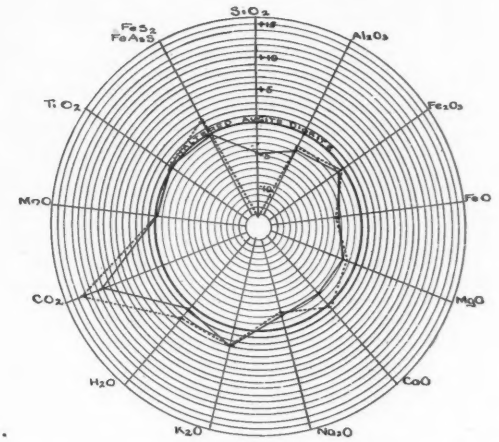

FIG. 38. Diagram illustrating gains and losses of each chemical constituent in terms of percentage of mass of original fresh augite-diorite. Distances between circles correspond to 1 per cent. Gains are outside, and losses are inside of heavy circle representing fresh augite-diorite. Dotted line represents altered augite-diorite from Woodchuck Vein, Lorne Mine. Solid line represents similar rock from the King Vein, Lorne Mine.

chemical constituent during the process of alteration are plotted, and compared with the analysis of the unaltered rock.

Similar pairs of chemical analyses of igneous rocks from Grass Valley and Juneau are compared in the same manner below. The accuracy of the figures may be questioned since the exact specific gravity of the rocks was not available, and had to be calculated from the data available in the literature. The calculation will serve, however, to give an approximate comparison of the meta-

[20] See also similar analyses, calculations and figures by Alan M. Bateman, Dissertation for the degree of Ph.D., Yale University Library, 1912, pp. 452–464.

TABLE II.[21]

COMPARISON OF ANALYSES OF FRESH AND ALTERED AUGITE DIORITE.

	A.	A_1.	1*A.*	1A_1.	2A_1.	3A_1.
SiO_2	49.34	35.06	145.00	99.92	−45.08	−15.34
Al_2O_3	17.57	15.62	51.60	44.45	− 7.15	− 2.41
Fe_2O_3	0.32	0.30	0.94	.85	− 0.09	− 0.03
FeO	8.84	5.58	26.38	15.90	−10.48	− 3.70
TiO_2	0.50	0.80	1.46	2.28	+ 0.82	+ 0.28
MnO	0.14	0.09	0.41	.26	− 0.15	− 0.05
NiO	0.06	.....	0.18	.....	− 0.18	− 0.05
MgO	6.01	4.83	17.90	13.75	− 4.15	− 1.41
CaO	9.84	10.76	28.90	30.70	+ 1.80	+ 0.61
K_2O	0.86	3.76	2.56	10.70	+ 8.14	+ 2.77
Na_2O	2.62	0.40	7.70	1.14	− 6.64	− 2.26
H_2O −	0.16	0.20	0.47	0.57	+ 0.10	+ 0.03
H_2O +	2.69	5.52	7.90	15.67	+ 7.77	+ 2.64
P_2O_5	0.06	0.06	0.18	0.18	.....	.....
FeS_2	0.47	1.91	1.38	5.45	+ 4.07	+ 1.37
Fe_7S_8	Traces	Traces	.....	.....	.....	.....
FeAsS	.....	0.52	.....	1.84	+ 1.84	+ 0.62
SO_3	0.03	0.03	0.09	.08	−40.01	.....
CO_2	0.42	14.72	1.26	42.00	+ 0.74	+13.70
	99.93	100.16	294.31	285.74	− 8.65	− 4.23
Determined sp. gravity	2.940	2.850	.....	.....	.....	.....
Explanation of method	.....	.....	Ax 2.940	A_1x 2.850	1A_1−1A	$\frac{2A_1}{2.940}$

A. Chemical analysis of unaltered augite diorite, Lorne mine, Bridge River, B. C., M. F. Connor, Analyst, 1922.

A_1. Chemical analysis of altered augite diorite, Woodchuck vein, M. F. Connor, Analyst, 1922.

1*A.* Constituents in grams in 100 cubic centimeters of unaltered augite diorite.

1A. Constituents in grams in 100 cubic centimeters of altered augite diorite.

2A_1. Gains and losses in the alteration of 100 c.c. of augite diorite to the same volume of altered product.

3A_1. Gains and losses of each constituent in percentage of mass of the original 100 c.c. of fresh augite diorite.

somatic changes which have taken place. In all cases it is assumed that in the alteration of the rocks there has been no important change in volume.

[21] The method used is that adopted by F. L. Ransome, "Geology and Ore Deposits of the Breckenridge Dist., Colo.," U. S. G. S. Prof. Paper 75, 1911, pp. 94–102.

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TABLE III.

COMPARISON OF ANALYSES OF FRESH AND ALTERED GRANODIORITE, NEVADA CITY, CAL.

	C.	C_1.	1*C.*	1C_1.	2C_1.	3C_1.
SiO_2	66.65	56.25	182.00	161.70	−20.44	−7.44
TiO_2	.38	.25	1.04	.72	− .32	−0.11
Al_2O_3	16.15	17.65	44.45	51.00	+ 6.65	+2.42
Fe_2O_3	1.52	.76	4.18	2.19	− 1.99	− .72
FeO	2.36	2.64	6.48	7.65	+ 1.17	+ .62
MnO	.10	.....	.27	.....	− .27	− .03
CaO	4.53	4.46	12.45	12.80	+ .35	+ .12
SrO	Trace	.....	.....	.....	.....	.....
BaO	.07	.03	0.19	.08	− .11	.....
MgO	1.74	1.69	4.78	4.88	+ .10	.....
K_2O	2.65	6.01	7.28	17.38	+10.10	+3.68
Na_2O	3.40	.30	9.35	.87	− 8.48	−3.08
Li_2O	Trace	.....	.....	.....	.....	.....
H_2O +	.18	.30	.50	.87	+ .37	+ .13
H_2O −	.72	2.36	1.98	6.82	+ 4.84	+1.76
P_2O_5	.10	.21	.27	.61	+ .34	+ .12
FeS_2	.02	2.87	.05	8.30	+ 8.25	+3.00
CO_2	.....	4.82	.....	13.92	+13.92	+5.06
	100.57	100.60	275.27	288.79	+14.48	−5.53
Calculated sp. gr.	2.750	2.889	.....	.....	.....	.....

C. Chemical analysis of unaltered granodiorite, Nevada City, Cal., W. F. Hillebrand, Analyst, 17th Ann. Rep. U. S. G. S., Pt. II., p. 38.

C_1. Analysis of altered granodiorite, Bellefountain mine, Nevada City, George Steiger, Analyst, *T. A. I. M. E.*, Vol. XXX., 1900, p. 666.

1*C.* Constituents in grams in 100 cubic centimeters of unaltered granodiorite; the chemical analysis having been recast to 100 per cent., calculation made with slide rule.

1C_1. Constituents in grams in 100 cubic centimeters of altered granodiorite.

2C_1. Gains and losses in grams in the alteration of 100 cubic centimeters of granodiorite to same volume of altered product.

3C_1. Gains and losses of each constituent in percentage of mass of the original 100 cubic centimeters of fresh granodiorite.

Specific gravity calculated from mineralogical composition. 17th Ann. Rep. U. S. G. S., Pt. II., p. 88. Lindgren, "Mineral Deposits," 1918, p. 520.

In Fig. 38 the dotted line illustrates the gains and losses shown in Table II., whereas the solid line refers to similar calculations by Alan M. Bateman,[22] of rocks from the same locality.

The diagram shows that in the alteration of the augite diorite

[22] *Loc. cit.*, p. 455.

there have been added carbon dioxide (in large amount), potash, sulphur, and arsenic; whereas silica, and the oxides of iron, aluminum, magnesium, and sodium have suffered losses.

TABLE IV.

COMPARISON OF ANALYSES OF FRESH AND ALTERED ALBITE DIORITE, JUNEAU, ALASKA.

	D.	D_1.	$1D$.	$1D_1$.	$2D_1$.	$3D_1$.
SiO_2	58.53	64.36	156.86	164.76	−10.10	− 3.77
Al_2O_3	17.74	18.18	47.50	46.50	− 1.00	− .37
Fe_2O_3	1.58	.64	4.24	1.64	− 2.60	− .97
FeO	1.46	.43	3.91	1.10	− 2.81	− 1.05
MgO	1.71	.28	4.58	.72	− 3.86	− 1.44
CaO	5.08	2.56	13.60	6.55	− 7.05	− 2.62
Na_2O	5.69	8.96	15.22	22.95	+ 7.23	+ 2.88
K_2O	3.90	.89	10.45	2.28	− 8.17	− 3.05
H_2O −	.18	.18	.45	.46	+ .01	.....
H_2O +	1.18	.55	3.16	1.41	− 1.75	− .65
TiO_2	.81	.17	2.17	.44	− 1.73	− .65
ZrO_2	.06	.03	.16	.08	− .08	− .03
CO_2	.90	1.62	2.41	4.15	+ 1.74	+ .65
P_2O_5	.27	.06	.72	.15	− .57	− .20
SO_3	.....	.07	.....	.18	+ .18	+ .07
MnO	.11	.11	.29	.28	− .01	.....
BaO	.07	.06	.19	.15	− .04	− .01
SrO	.05	.04	.13	.10	− .03	− .01
FeS_2	.96	.97	2.54	2.48	− .06	− .02
	100.28	100.16	268.58	256.38	−30.20	−11.24
Calculated specific gravity	2.68	2.56	.....	.....	.....	.....

D. Chemical analysis of relatively fresh albite-diorite from Treadwell mine, George Steiger, Analyst, Bull. U. S. G. S. No. 287, p. 101.

D_1. Chemical analysis of slightly altered albite-diorite from Treadwell mine, Idem., p. 101.

For explanation of other columns see Tables II. and III. Specific gravities calculated from mineralogical compositions. U. S. G. S. Bull. 287, p. 103.

The silica which has been lost has probably contributed to the vein filling; and the iron and magnesium of the ferromagnesian minerals of the fresh rock have combined with the newly introduced sulphur and arsenic to form the sulphides so conspicuous in the extremely altered rock. The bleached character of the altered rock is explained in this way. The mineralizing solutions

must therefore have been warm carbonated alkaline waters containing gold, sulphur, and arsenic.

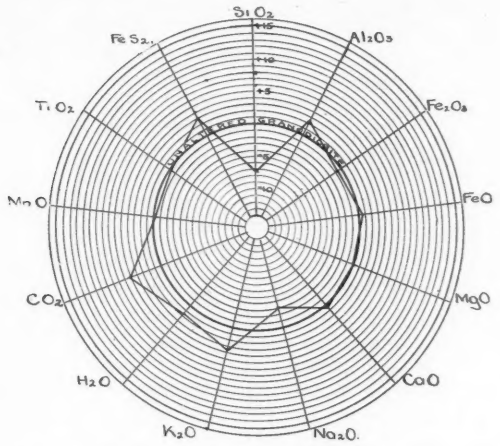


FIG. 39. Diagram illustrating gains and losses in the alteration of granodiorite at the Bellefountain Mine, Nevada City, California. For explanation of diagram see Fig. 38.

When the diagrams of Figs. 38 and 39 are compared, the results of the alteration of the rocks at Grass Valley, Cal., and the Bridge River District are strikingly similar. Therefore it is reasonable to infer that the vein solutions were essentially of similar composition.

Fig. 40, which illustrates the result of alteration at Juneau, Alaska, may be used only with great reservations. The chemical analyses of albite diorite given in Table IV. are by no means entirely suited to the purpose, since there was no analysis available of extremely altered rock. The diagram, however, suggests a similarity in results of the alteration of the albite diorite to that of granodiorite at Grass Valley and to augite diorite in the Bridge River District. The only conspicuous differences are the addition of soda and the loss in potash and calcium oxide.

Microscopic examination of altered albite diorite[23] has shown that albite has been formed in the rock at the expense of the original potash-bearing feldspar, and part of the soda of the secondary albite is considered to have been introduced by the vein solutions.

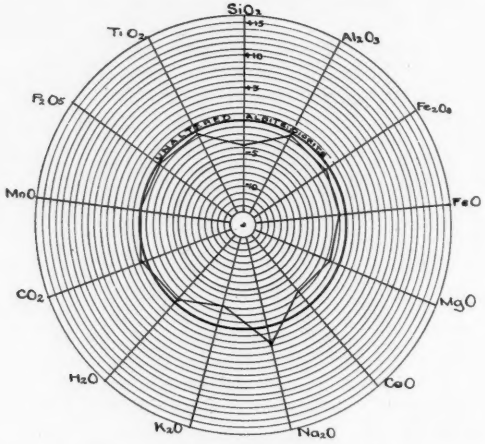


FIG. 40. Diagram illustrating gains and losses in the alteration of albite-diorite from the Treadwell mine, Southeastern Alaska. For explanation of figure see Fig. 38.

Origin of the Vein Solutions.—The solutions from which the vein minerals were precipitated are believed to be genetically related to the augite diorite, the veins representing the last phase of magmatic differentiation of the magma. The parent magma probably cooled with such excessive slowness that it produced a differentiate consisting almost entirely of pure albite.[24] Evi-

[23] Spencer, A. C., *loc. cit.*, p. 114.

[24] N. L. Bowen in his paper on "The Melting Phenomena of Plagioclase Feldspars" (*Amer. Jour. Sci.*, Vol. 35, 1913, p. 597), has shown experimentally that if a melt of plagioclase of the composition Ab_1 An_1 at 1500 degrees Centigrade, be cooled with *excessive* slowness, crystals of the composition Ab_{18} An_{81} begin to separate out at 1450 degrees, and theoretically the composition of the crystals will change continuously toward Ab_1 An_1, and their

dence of this is the occurrence of albitite dikes, the rock of which is made up almost entirely of minute interlocking grains and tabular crystals of albite, partly altered to sericite. Similar rocks, although of rare known occurrence, have been found in the Mother Lode district in the Sierra Nevada, Cal.,[25] and elsewhere.[26]

After the albite differentiate separated out, the remaining liquor contained the silica that was not required to combine with the soda and alumina of the albite and also all the potash, the latter not combining with soda, alumina, and silica to form other feldspars. This resulting liquor under intense pressure was probably made exceedingly fluid by the addition of large amounts of magmatic water, and thus was enabled to permeate the wall rocks to effect the alteration generally observed.

The presence of abundant magmatic water to produce such aqueous solutions may be accounted for by the occurrence of a magmatic reservoir, remaining molten long after its satellitic intrusives had solidified, underlying the whole region.

Day and Shepherd[27] have shown that water is an important constituent of volcanic gases and that its magmatic source is exceedingly probable; and the order of crystallization of the constituents of granular igneous rocks can be best explained by admitting the existence of more water in the magma before its consolidation than is shown in the analysis of the resulting rock.[28] It is therefore assumed that magmatic water, resulting from the crystallization of the magma, and from igneous emanations, con-

amount will increase down to 1287 degrees where the whole mass will consist of crystals having the composition Ab_1 An_1. The liquid remaining will continue gradually crystallizing below 1287 degrees, and, if the cooling is at the proper rate, the final crystals may be nearly pure albite $Ab_{98.5}$ $An_{1.5}$.

In another article (*Jour. of Geol.*, Vol. 23, 1915, Supp. to No. 8, p. 39) the same author has stated that under the proper circumstances a mixture having the original composition of a gabbro may yield a final liquid of more than 90 per cent. albite.

[25] Turner, H. W., 17th Ann. Rep. U. S. G. S., 1895–6, Pt. I., p. 603–665.

[26] Duparc and Pearce, *Compt. Rendu*, 140, 1908, p. 728. Tilley, C. E., *Trans. Roy. Soc. of S. Australia*, Vol. XLIII., 1919, pp. 316–341.

[27] "Water and Volcanic Activity," *Bull. G. S. A.*, Vol. 24, 1913, p. 606.

[28] Spencer, A. C., "Magmatic Origin of Vein-forming Rocks," *T. A. I. M. E.*, Vol. 36, 1905, p. 366.

stituted a great part of the ascending heated solutions that altered the wall rock and formed the veins.

Abundant silica to form the gangue material must have been present in the magmatic liquor remaining after the albite differentiate had crystallized out. A certain amount was probably contributed by the wall rock during its alteration by the solutions, since the augite diorite suffered a loss in silica during the process.

Relative Age of the Veins.—A sufficient length of time must have intervened between the intrusion of the augite diorite and the formation of the veins to have permitted of the solidification of the rock to such an extent that it would yield to deforming stresses by fracturing. The greater the thickness of overlying sediments the longer would be the time required for solidification. We have no means of estimating the thickness of this overburden, but it would be difficult to account for so great a thickness as to retard the cooling for any great length of time. It is considered, then, that the augite diorite cooled soon after its intrusion and that the deforming stresses causing the fissuring acted about the same time, the intrusion of the albite differentiate of the same magma as albitite dikes, indicating that the augite diorite could not have been solidified for a long time before they were intruded.

This intrusion of the albitite dikes contributed to the greater ease with which the fissures, now filled with quartz, were made, since the veins often conform with the dikes, occurring along the same lines of weakness and in the same fissures. The veins are younger than the dikes because they often cut across them, and are believed to represent the last manifestation of igneous activity of the augite diorite magma, and therefore of the same general age, but slightly younger than that of the intrusive.

CONCLUSIONS.

The gold-bearing quartz veins of the Bridge River district are essentially similar in character, mineralogy, and geological association with those of Grass Valley, Cal., and South-eastern Alaska. The alteration of the wall rocks, which extends to distances up to

six feet, indicates that the metasomatic processes that were active were similar to those in the above-named districts, so it is considered that the vein solutions were essentially similar. According to Lindgren[29] the veins are classified as "Sericitic and Calcitic Gold Veins."

In correlating the age of the veins (Table I.) the present knowledge, as gleaned from the literature, permits of no absolute agreement for the three districts. Concerning the age of the diorites at Juneau, Spencer[30] states: "It is now possible to fix the age of these intrusions as Middle Cretaceous," and goes on to say that "the diorites have not been observed cutting these Lower Cretaceous rocks, but the period of invasion is regarded as later than the general folding, because the structure of the sedimentary rocks has so completely determined the boundaries of the intrusive masses of diorite."

Similarly in the Bridge River district there is some uncertainty regarding the exact age of the augite diorite intrusions, since the Lower Cretaceous rocks have been eroded from the localities where the augite diorite occurs, and it is not certain whether or not it intruded those sediments before they were eroded. Future geological work about the margins of the great Coast Mountains batholith may bring the relative ages of gold-quartz veins of the three districts into closer agreement, since there is such a striking similarity between them, suggesting a common and contemporaneous origin.

GEOLOGICAL SURVEY OF CANADA,
OTTAWA, CANADA.

[29] Lindgren, Waldemar, "Metasomatic Processes in Fissure-veins," *T. A. I. M. E.*, Vol. XXX., 1920, p. 665.

[30] Spencer, A. C., *loc. cit.*, p. 15.

GENERAL FORMULÆ FOR THE DETERMINATION OF THICKNESS AND DEPTH OF STRATA.

W. Armstrong Price.

The arrangement of the formulæ for the determination of thickness and depth of strata, here presented, was developed primarily[1] for use in the field. It is strictly applicable only to traverse lines along which the dip and strike of the strata are approximately constant, that is, when the two surfaces bounding any given stratum may be considered as two parallel planes, within the limits of the particular traverse unit involved in the problem.

The attempt has been made to express the formulæ in simple terms so that they may be readily retained in the memory.

It has been found that when determinations of thickness or depth are to be made from the field notes it is advantageous to combine all the necessary operations into two general formulæ, one for thickness and one for depth. This method has been found in practice to promote uniformity both in making the field observations and in the later computations of the stratigraphic elements. With the use of the suggested note form, the likelihood of omissions being made in taking the field observations is reduced, since the column headings (see Table I.) constitute memoranda of the necessary measurements.

In the formulæ, horizontal distances and altitude measurements are employed in preference to slope measurements, in accordance with the best surveying practice. Full account is taken, however, of cases in which slope measurements are useful or preferable, and formulæ are developed for their use.

[1] The thickness formulæ and the note form (Table I.) were developed by Charles K. Swartz, with minor modifications by the writer. The depth formulæ and certain other features have been adapted from the works of Palmer and Smith, cited herein, and from C. W. Hayes' "Handbook of Field Geology."

PUBLISHED FORMULÆ.

In Textbooks.—The subject of the determination of thickness and depth, in many textbooks and handbooks, is either omitted or is inadequately treated. In most handbooks, tables of depth and thickness are given without mention of the corrections necessary where the traverse is not at right angles to the strike and where the ground is sloping. These omissions and the partial treatment given the subject by some textbooks have confused the student and have been responsible for many poorly-measured sections. This situation, in part, has prompted the present discussion of a usable trigonometric method in which the aim has been to condense the formulæ sufficiently for field use.

In the Journals.—The subject has been well treated in the scientific journals, but from different viewpoints, by a number of writers. Only two of these articles will be noted here. Convenient charts for the graphic determination of depth, thickness, and the projection of the dip have been published by Palmer,[2] who also develops the formulæ upon which the charts are based. Palmer's charts and formulæ cover all the possible cases. The formulæ are not developed for field use, but the reprint of the charts by " Lefax " can be readily used in the field. Where these charts are available, their use, as has been shown by Palmer, will effect a decided saving in time over that required by the trigonometric method, which involves the use of logarithmic tables. These charts may be used in conjunction with the formulæ and the note form of the present discussion. Graphic methods and trigonometric formulæ developed by W. S. Tangier Smith[3] for the solution of geologic problems include the determination of thickness and depth. These graphic methods are not, however, adapted to field use and the trigonometric formulæ require the measurement of slope angles and distances which it is seldom convenient to measure in geologic field work. The measurements

[2] Palmer, H. S., Econ. Geol., Vol. 14, p. 346, 1919; U. S. Geol. Surv. Prof. paper 120G, 1919, and Lefax [Philadelphia], 51; 9–85.

[3] Econ. Geol., 1914, vol. IX., No. 1, pp. 25–66; and No. 2, pp. 136–152; with a bibliography of graphic solutions of geologic problems.

most readily and easily obtained under a variety of topographic conditions and of field equipment are the horizontal and vertical components of the distance. It is upon these that Palmer's graphic charts and the following trigonometric method are based.

THE METHOD.

The group of strata whose thickness and structure is desired is studied along the route yielding the best and most continuous exposures. A continuous traverse is then made along the route selected. The compass bearings of the traverse, the horizontal distances, and the dips and strikes are measured and the altitudes of all stations are determined. Traverse stations should be established at each pronounced change in the slope of the ground, at both boundaries of all lithologic units, and at all points where there is a change in either the strike, the dip, or the bearing of the traverse. The measurements made are entered in the proper columns in the suggested tabular form for recording the notes, Table I. Full descriptions of the lithologic units crossed between successive traverse stations are made on other pages in the notes, and the page references to these descriptions are recorded in the table with brief descriptions of the strata. To determine the thickness and depths, substitution of the proper measurements can then be conveniently made in the formulæ.

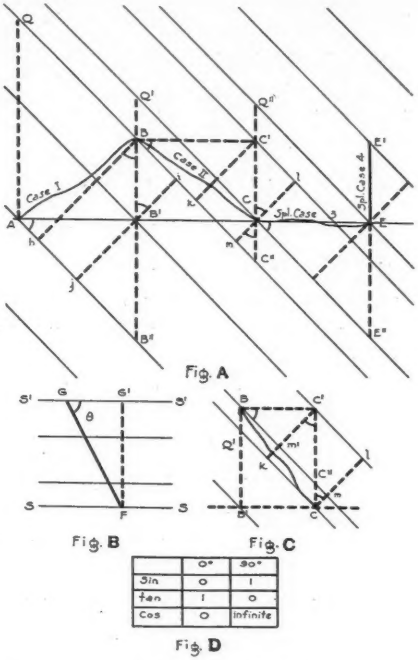
SPECIAL CASES.

Special (limiting) cases arise when one or more traverse measurements are 0, 0° or 90°, as follows:[4]

1. Traverse parallel to strike (with or without vertical component) ..... $\theta = 0°$
2. Traverse perpendicular to strike ..... $\theta = 90°$
3. Traverse horizontal (no vertical component) ..... Vert. $= 0$
4. Traverse vertical (no horizontal component) ..... Hor. $= 0$
5. Traverse through horizontal strata ..... Dip $= 0°$
6. Traverse through vertical strata ..... Dip $= 90°$

[4] See under *The Formulæ*, below, for notation used here.

By use of the general formulæ here presented it becomes possible to make determinations of depth and thickness under these special cases without developing a separate formula for each case. The values of the trigonometric functions for 0° and 90°



	0°	90°
Sin	0	1
Tan	1	0
Cos	0	infinite

FIG. 41. *A, B, C, D.* To illustrate dip and thickness of strata.

(see Fig. 41, *D*), when substituted with the other measurements in their proper places in the formulæ, will give the true values of the depth and thickness under the special cases.

THE FORMULÆ.

To find the thickness (T) of a stratum, or of a group of strata, between the ends of a line of traverse:

1. Determination of Thickness.

Given the following measurements: **Symbols.**

Horizontal distance of traverse across the strike..... **Hor.**
Direction of traverse .....
Strike and dip of the strata..... **Dip.**
Difference in elevation between ends of traverse line..... **Vert.**

From the above is obtained:

Angle between horizontal direction of traverse and the strike..... θ

By inspection of Fig. 1, *A, B, C,* it is seen that the following formula covers all cases:

General Formula for Thickness of Strata:

$$\mathbf{T = Hor. \times \sin \theta \times \sin Dip \pm Vert. \times Cos\ Dip.}$$

Rules for Vertical Correction:

Algebraic sign of **Vert. x cos Dip** is:

+, when the ground slopes **against** the dip (dip and slope angles in different quadrants), **Case I,**

—, when the ground slopes **with** the dip (dip and slope angles in same quadrant), **Case II.**

Vertical correction is:

0, when the traverse is horizontal and through inclined strata, **Special Case 3;**

0, when the traverse is in vertical strata, **Special Case 6.**

2. Determination of Depth (and Height).

To find the Depth (D) at one end of a line of traverse to a stratum which outcrops at the other end, **or the height** (H) of the projection of a stratum at the opposite end of a line of traverse from the outcrop.

Measurements Given: The same measurements and symbols as for thickness, except that "**Hor.**" signifies here the horizontal distance of traverse from the outcrop of the stratum to which it is desired to compute the depth.

By inspection of Fig. 41, *A, B, C,* it is seen that the following formula covers all cases:

General Formula for Depth (and Height):

$$\mathbf{D = H = Hor. \times \sin \theta \times \tan Dip \pm Vert.}$$

Rule for Algebraic Sign of Vert. The same as for thickness.

Height. It is readily seen from the figures that the projected heights, *AQ*, *BQ'*, and *CQ''*, are equal to the depths, *BB''*, *CC''*, and *EE''*, respectively.

Caution—When Dip of Strata and Slope of Ground are Nearly the Same.—In this case a graphic cross-section with the same horizontal and vertical scales should be drawn in order to determine the true stratigraphic relations. The formulæ should be applied after an analysis of this cross-section.

The necessity for this precaution will be seen from a study of Case II., in Fig. 41, *A*, *C*. In Fig. 41, *A*, Case II., the stratum **BC''**, outcropping at **B**, is beneath the surface of the ground at **C**; while in Fig. 41, *C*, the stratum **BC''**, outcropping at **B**, has been eroded at **C** and its projected horizon passes above the surface of the ground at that point. In Fig. 41, *C*, where the slope angle is greater than the angle of dip, the values of **T** and **D** are algebraically negative. When **T** is negative the minus sign has no significance, but a negative depth must be interpreted to mean height **(— D = H)** which signifies that the stratum, or its horizon, lies overhead at the point under consideration.

3. Use of Slope Measurements in Depth and Thickness Determinations.

A. Use of the Slope Angle Alone.—The general formulæ are based on the determination and use of horizontal distances and vertical elevations. It is believed that the cases in which it will be inexpedient to determine these traverse elements will be relatively infrequent. At times, however, it may be simpler and more convenient to measure slope angles and distances. In the following cases such measurements may be profitably employed:

a. In Place of the Horizontal Distance.—The slope angle may be measured in place of the horizontal distance when trav-

ersing short, steep slopes over rough talus deposits, or through thick vegetation, or when measuring across swift streams, especially when one bank is a cliff. In these cases measurements of the slope distances would usually be somewhat inaccurate but the vertical elevations could be determined with the usual degree of accuracy.

b. In Place of the Difference in Altitude.—The slope angle and horizontal distance may be measured when accurate means are not available for determining relative altitudes directly.

c. Slope Measurements to Check Errors in Horizontal or Vertical.—Accumulated error in the horizontal distances may occur in traverses up long, steep slopes. In the same way, errors in altitude measurements are liable to accumulate when the geologist is hand-levelling over long low slopes. In these two cases the slope angles should be measured, and the thicknesses determined through their use should be employed to check those obtained by the use of the horizontal and vertical distances.

In any of these cases, *a, b,* or *c,* substitution may be made in the general formulæ for depth and thickness as follows:

Given the Angle of Slope of Traverse (In Cases I. and II.):

Instead of **Hor.** substitute **Vert. x cot Slope Angle;**

Instead of **Vert.** substitute **Hor. x tan Slope Angle.**

B. Use of Both Slope Angle and Slope Distance.—It is not usually convenient to measure slope distances, except when making a chain traverse—a method rarely used in geological field surveying. For very short courses when a pocket tape (50 to 100 foot) can be used in place of a cumbersome surveyor's chain this method may be applied. In this case the following will be used in place of the general formulæ for thickness and depth:

Given Both the Angle of Slope of Traverse and the Slope Distance (In Cases I. and II.):

Thickness:

$$\mathbf{T = Slope\ Dist. \times \sin (Dip \pm Slope\ Angle).}$$

Depth:

$$\mathbf{D = Slope\ Dist. \times \sin (Dip \pm Slope\ Angle) \times \sec Dip.}$$

Rule for Slope Angle:

Algebraic sign of Slope Angle is:

+, in **Case I.**,
—, in **Case II.**

Slope Angle is:

0, in **Special Case 3.**

TABLE I.

T = Hor. × sin θ × sin Dip ± Vert. × cos Dip. D → Hor. × sin θ × tan Dip ± Vert.				Rule: Ground slopes against dip, +. Ground slopes with dip, —.							Ground level, Vert. = 0.		
Line		Description of Strata (Brief) with Formula and Case Used.	Slope Dist.	Slope Angle.	Traverse Distance (Horiz'l).	Traverse Bearing.	Acute Angle θ.	Strike.	Dip.		Elevation End of Line.	Thickness.	Depth.
From Sta.	To Sta.												

PROOF OF THE FORMULÆ.

Proof of 1. Thickness.

Case I. When the ground slopes "against" the dip; that is, when the angle of dip and the angle of slope of the traverse are in different quadrants; by reference to Fig. 41, *A*,

$$T = Bh = jB' + B'i$$
$$= AB' \times \sin B'Aj + BB' \times \cos BB'i$$

or

$$T = \text{Hor.} \times \sin \text{Dip} + \text{Vert.} \times \cos \text{Dip},$$

which is true in Special Case 2, above, when the traverse is at right angles to the strike.

When the traverse (GF, in Fig. 41, B) is at an acute angle (θ) with the strike (SS, $S'S'$), the length of the line $G'F$, which is the projection of GF on a line at right angles to the strike, must be obtained and this value substituted for AB' in the above formula. Thus:

$$G'F' = GF \times \sin G'GF = \text{Hor.} \times \sin \theta.$$

Then, substituting for AB',

$$T = \text{Hor.} \times \sin \theta \times \sin \text{Dip} + \text{Vert.} \times \cos \text{Dip}.$$

Case II. When the ground slopes "with" the dip; that is, when the angle of dip and the angle of slope of the traverse are in the same quadrant; by reference to Fig. 41, *A*,

$$T = m\dot{C} = ml - Cl = kC' - Cl$$
$$= BC' \times \sin C'Bk - C'C \times \cos C'Cl,$$

or

$$T = \text{Hor.} \times \sin \text{Dip} - \text{Vert.} \times \cos \text{Dip},$$

which is true in Special Case 2, above, when the traverse is at right angles to the strike.

Under Case I., when traverse is at an acute angle (θ) with the strike (see Fig. 41, *B*), the horizontal distance must be multiplied by sin θ and the formula becomes:

$$T = \text{Hor.} \times \sin \theta \times \sin \text{Dip} - \text{Vert.} \times \cos \text{Dip}.$$

A Negative Value of T.—In Case II., when the slope angle is greater than the angle of dip (Fig. 41, *C*), this value of T is algebraically negative. The arithmetical value of T, however, is not affected and the formula is still applicable in the determination of thickness.

From Fig. 41, *C*,

$$T = Cm = Cl - ml = kC' - m'C'$$
$$= CC' \times \cos CC'k - BC' \times \sin C'Bm'$$

or

$$T = \text{Vert.} \times \cos \text{Dip} - \text{Hor.} \times \sin \text{Dip}$$

or

$$-T = \text{Hor.} \times \sin \text{Dip} - \text{Vert.} \times \cos \text{Dip}.$$

Proof of 2. Depth (and Height).

Case I.—When the ground slopes "against" the dip; that is, when the angle of dip and the angle of slope of the traverse are

in different quadrants; by reference to Fig. 41, *A*,

$$D = BB'' = B'B'' + BB'$$
$$= AB' \times \tan B'AB'' + BB',$$

or

$$D = \text{Hor.} \times \tan \text{Dip} + \text{Vert.},$$

which is true in Special Case 2, above, when the traverse is at right angles to the strike.

When the traverse (*GF*, in Fig. 41, *B*) is at an acute angle (θ) to the strike, the length of the line *G'F* must be obtained and this value substituted for *AB'* in the above formula.

$$G'F = GF \times \sin G'GF = \text{Hor.} \times \sin \theta.$$

Then,

$$D = \text{Hor.} \times \sin\theta \times \tan \text{Dip} + \text{Vert.}$$

Case II. When the ground slopes "with" the dip; that is, when the angle of dip and angle of slope of the traverse are in the same quadrant; by reference to Fig. 41, *A*,

$$D = CC'' = C'C'' - C'C,$$
$$= BC' \times \tan C'BC'' - C'C,$$

or

$$D = \text{Hor.} \times \tan \text{Dip} - \text{Vert.},$$

which is true in Special Case 2, above, when the traverse is at right angles to the strike.

Under Case I., when the traverse is at an acute angle (θ) with the strike (see Fig. 41, *B*), the horizontal distance must be multiplied by sin θ and the formula becomes:

$$D = \text{Hor.} \times \sin\theta \times \tan \text{Dip} - \text{Vert.}$$

A Negative Value of D.—In Case II., when the slope angle is greater than the angle of dip (Fig. 41, *C*), this value of *D* is algebraically negative,

$$D = CC'' = C'C - C'C'',$$

or

$$-D = C'C'' - C'C.$$

In this instance $-D$ is seen to mean height (H), since the stratum which outcrops at B (or its horizon) is overhead at C; hence

$$H = -D = \text{Hor.} \times \sin \theta \times \tan \text{Dip} - \text{Vert.}$$

Since $CC'' = BQ'$, H equals the depth to stratum CQ' below the point B, as well as the height of stratum Bm above the point C.

Proof of 3. Use of Slope Measurements in Depth and Thickness Determinations.

A. Use of the Slope Angle Alone. In Fig. 41, *A, Case I.*

Hor. $= AB' = BB' \times \cot BAB' =$ Vert. $\times$ cot Slope Angle.

Vert. $= BB' = AB' \times \tan BAB' =$ Hor. $\times$ tan Slope Angle.

In Case II., Fig. 41, *A* or *C*,

Hor. $= BC' = CC' \times \cot C'BC =$ Vert. $\times$ cot Slope Angle.

Vert. $= CC' = BC' \times \tan C'BC =$ Hor. $\times$ tan Slope Angle.

B. Use of Both Slope Angle and Slope Distance.

Thickness:

Case I. $Bh = AB \times \sin (B'AB'' + BAB')$

or

$$T = \text{Slope Dist.} \times \sin (\text{Dip} + \text{Slope Angle}).$$

Case II. $Cm = BC \times \sin (C'BC'' - CBC')$

or

$$T = \text{Slope Dist.} \times \sin (\text{Dip} - \text{Slope Angle}).$$

Depth:

As it can be seen from an inspection of triangles $B''Bh$ (Fig. 41, *A*) and $C''Cm$ (Fig. 41, *A, C*), the mutual relationship of T and D in all cases is expressed by the following equation:

$$T = D \times \cos \text{Dip}.$$

To obtain values for D under the two general cases, we substitute this value of T in the formulæ just developed for thickness, as follows:

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Case I.

$D \times \cos \text{Dip} = \text{Slope Dist.} \times \sin (\text{Dip} + \text{Slope Angle})$,

or

$D = \text{Slope Dist.} \times \sin (\text{Dip} + \text{Slope Angle}) \times \sec \text{Dip}$.

In like manner,

Case II.

$D = \text{Slope Dist.} \times \sin (\text{Dip} - \text{Slope Angle}) \times \sec \text{Dip}$.

DALLAS, TEXAS.

SUPERGENE PROCESSES AT NEIHART, MONT.

M. E. HURST.[1]

INTRODUCTION.

Amid the Little Belt mountains of central Montana lies the Neihart district which, several decades ago, was conspicuous among the silver-producing regions of the West.

After a lapse in mining activity extending over a number of years interest in the district has recently been revived with the result that the annual production of silver in Cascade County now exceeds 500,000 ounces.[2]

During 1898–99 W. H. Weed[3] studied the area. In his report he stated that the deposits were silver-bearing fissure veins in a region of Archean granite and pre-Cambrian quartzite with intrusive diorite and porphyry. In these deposits he recognized the importance of secondary enrichment and stated that polybasite (really pearceite), pyrargyrite, and native silver were largely responsible for the phenomenal value of the ores. He considered these minerals to be of supergene origin, although he expressed the opinion that the polybasite might be a constituent of the original ore.

In 1913, E. S. Bastin[4] applied metallographic methods to a specimen of rich silver ore collected by Weed from the 300-foot level of the Big Seven mine. As a result of this investigation he reached the conclusion that the metasomatic replacement of galena by polybasite had been of prime importance in the formation of the supergene zone of enrichment. This limited study failed to reveal any polybasite of hypogene origin.

[1] Introduced by Waldemar Lindgren. Paper presented at the Amherst Meeting of the Society of Economic Geologists, Dec. 30, 1291.

[2] Mineral Resources of the U. S., 1920. Part I, p. 207.

[3] Twentieth Annual Report, U. S. Geological Survey for 1898–'99, part III., 401–423.

[4] Bastin, E. S., ECON. GEOL., vol. 8, 1913, p. 59.

The occurrence of polybasite as a hypogene mineral has received little credence, for, in this rôle, it is relatively inconspicuous and so has largely escaped attention. In 1909, J. E. Spurr[5] insisted that large masses of polybasite ore in the Molly Gibson mine at Aspen, Colo., were hypogene in origin, but this assertion has not remained unquestioned. The essence of this paper will be, therefore, to present evidence in support of the thesis that polybasite of hypogene origin was the ultimate source of the silver which contributed to the formation of the supergene silver sulphides in the Neihart district.

GENERAL DESCRIPTION.

The exceptionally interesting suite of specimens described in this paper was obtained by the Massachusetts Institute of Technology through the courtesy of Mr. C. L. Whittle, of Boston. At the suggestion of Professor Lindgren, the writer undertook the study of this suite in an endeavor to throw more light on the processes of enrichment in the Neihart district. Of particular interest are the specimens from the various levels of the Moulton claim as this property is being operated at present by the Cascade Consolidated Silver Mines Company.

At a depth of 70 feet from the surface of the Moulton claim the much fractured and altered country rock is traversed by numerous narrow stringers of ore. These veinlets consist principally of zinc blende, with some galena, pyrite, and chalcopyrite. They seem to have been deposited partly as fillings along fracture planes and partly by replacement of the inclosing rock. The sulphides frequently occur as thin films or coatings on the irregular planes of fracture, but are unaccompanied by any silver minerals of supergene origin.

Specimens from the 300-foot level of the same claim exhibit a mineral association similar to that described above, but in addition to the massive aggregates of these minerals there is a marked tendency toward crystallization in open cavities, which are here

[5] Spurr, J. E., "Ore Deposition at Aspen, Colo.," ECON. GEOL., vol. 4, 1909. pp. 301–320.

quite abundant. Chalcopyrite and galena are particularly well crystallized, the latter often replacing the former, while pyrite and zinc blende occur more rarely. These sulphides are later than the delicate quartz crystals which line such open spaces and have every appearance of being hypogene.

The most instructive specimen, measuring some 6 inches square and 5 inches in thickness, was taken from the 500-foot level. On one side of the specimen there is an intimate mixture of coarsely crystallized galena and zinc blende with lesser amounts of pyrite and chalcopyrite. This material, being typically hypogene in character, was used in the preparation of polished sections. The sulphides are inclosed in a gangue of barite, which forms the bulk of the specimen. On one surface of the barite are several open cavities lined with quartz crystals. In these cavities are the corroded remnants of crystals of hypogene pyrite, galena, and chalcopyrite. Partly covering these early sulphides, as well as the quartzose linings, are radiating masses of pyrite of pronounced octahedral habit. Partly replacing the earlier sulphides and encrusting other portions of the vugs are masses of pearceite and proustite undoubtedly of supergene origin. The pearceite frequently occurs in hexagonal prisms, having, on the basal planes, the triangular markings so characteristic of this mineral.

The specimens described above point to the following succession of events in the history of this deposit:

1. The deposition of barite as fissure filling.
2. The formation of open cavities in the barite and in the country rock by solution and fracturing and the deposition of quartz crystals on the walls.
3. The introduction of pyrite, chalcopyrite, sphalerite, and galena, which
   - (*a*) replace the barite filling;
   - (*b*) occur as excellent crystals on the quartzose linings of the vugs;
   - (*c*) fill fracture planes in the country rock.

4. The deposition of radiating masses of pyrite, crystalline pearceite, and some proustite in such cavities as were accessible to the supergene solutions.

HYPOGENE POLYBASITE.

Polished sections of the hypogene ore from the 500-foot level of the Moulton claim were studied in particular and the following succession of minerals observed. Pyrite was the first sulphide to be deposited and frequently shows distinct crystal outlines. A generation of quartz crystals accompanied or preceded the introduction of the pyrite. Chalcopyrite and zinc blende followed and caused the shattering of the pyrite and partial corrosion of the quartz crystals. Galena filled in the interstices, partly replaced the earlier sulphides, and accentuated the shattering of the pyrite. As a last phase of hypogene action polybasite was introduced and replaced the galena in part.

The polybasite was identified by microchemical and blowpipe tests and was found not only associated with the original ore from the deepest level, but also under similar conditions near the surface. The masses of polybasite are scattered with extreme irregularity throughout the galena, they possess no crystal form, and seem to be entirely independent of such structural features as cleavage directions or planes of contact between the various minerals. These masses vary greatly in size and shape, sometimes replacing whole areas of galena and frequently inclosing others. (Plate V., *d*.)

The metasomatic replacement of galena by polybasite, described by Bastin as occurring in the Big Seven mine, proceeded by means of such physical directions as were most readily permeated by the descending silver solutions. This supergene polybasite was accompanied by pyrargyrite and native silver, which are totally absent in the hypogene ore from the Moulton claim. Etching failed to reveal any argentite in the galena from this claim. This lack of criteria suggestive of supergene processes, in addition to the typically hypogene association of the polybasite, serves to establish its origin from ascending solutions. It is therefore fair to assume that this polybasite was the ultimate source of the silver which later was involved in the processes of enrichment.

SUPERGENE PROCESSES.

Weed, in his report on the Neihart ores, stated that:

An examination of numerous specimens from the Florence and Big Seven mines shows that while polybasite is possibly a constituent of the primary ore, its most common occurrence, like that of pyrargyrite, is as a secondary mineral.[6]

It has been pointed out that polybasite is a constituent of the original ore, and so it remains to trace the development of the supergene silver minerals. In describing a specimen of galena from the Florence mine Weed[6] proceeds as follows:

The galena is etched and leached so that, on part of the specimen, the surface shows a crust of about 1/16 to 1/8 inch thickness consisting of a spongy residue, or a skeleton of the galena. This spongy mass consists largely of polybasite left behind as the more soluble lead was leached out.

Although this occurrence of polybasite was not observed in the suite of specimens available for this study, yet it may be assumed from Weed's description that the polybasite left behind in the leaching process was of hypogene origin. The oxidation of pyrite no doubt contributed ferric sulphate and free sulphuric acid to the circulating waters which attacked the galena, leaving the residual polybasite behind. The latter, however, would slowly be decomposed with the addition of silver and antimony to the solutions.

G. S. Nishihara[7] has shown that such descending solutions would become alkaline through the neutralizing actions taking place in their downward course. The investigations of F. F. Grout[8] and L. G. Ravicz[9] show that arsenic or antimony are most likely present in solution as alkaline sulphides and that intermingling of such alkaline solutions with acid silver sulphate waters would cause the precipitation of a compound whose composition depends on the relative amounts of silver and antimony or arsenic present.

In the case of the Moulton deposit a stage was reached in the

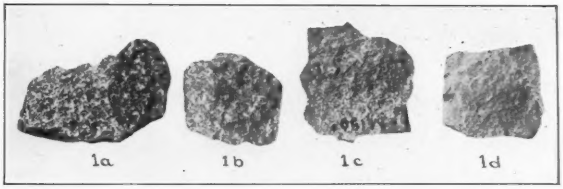
[6] *Trans. A. I. M. E.*, 1900, "The Enrichment of Gold and Silver Veins," p. 435.

[7] Nishihara, G. S., ECON. GEOL., vol. 9, 1914, pp. 743–757.

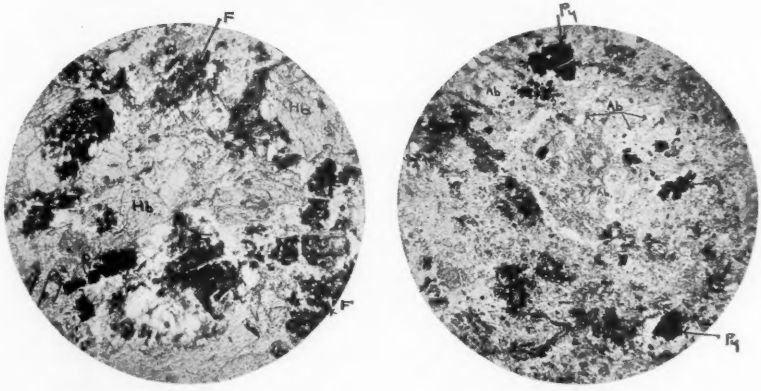
[8] Grout, F. F., ECON. GEOL., vol. 8, 1913, pp. 407–433.

[9] Ravicz, L. G., ECON. GEOL., vol. 10, 1915, pp. 368–389.

a



b



c *d*

a. Photographs of vein quartz showing the ribbon structure which is characteristic of the richer veins.

b. Photographs showing progressive alteration from fresh augite diorite to extremely altered rock adjacent to the vein. (¼ natural size.)

c. Microphotograph (× 17) in polarized light of relatively fresh augite diorite from the Lorne Mine.

d. Microphotograph (× 17) in polarized light of greatly altered augite diorite showing its generally characterless appearance.

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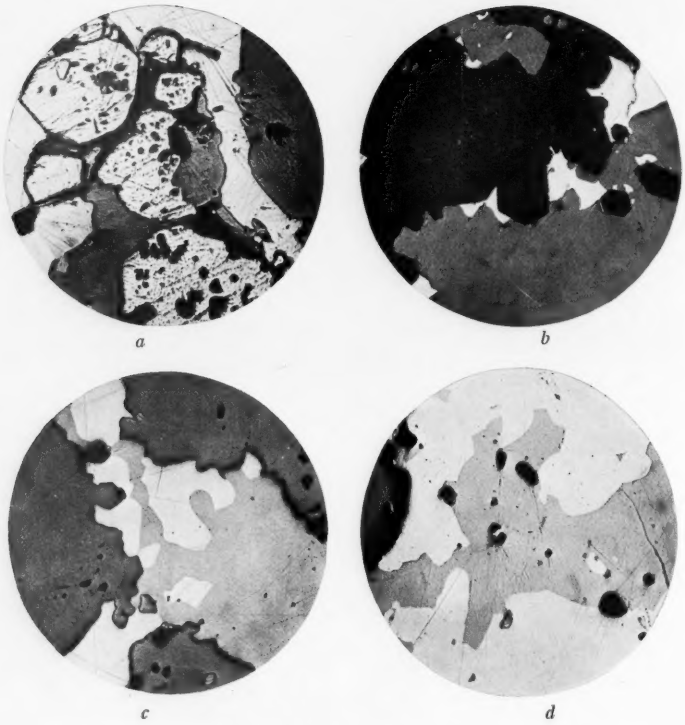

a

b

c

d

a. Sphalerite (dark) replacing pyrite (high relief). Polybasite (gray) in galena (light). ×65.

b. Sulphides replacing quartz (black). Sphalerite (dark gray), galena (white), chalcopyrite (white with slight relief). ×65.

c. Polybasite (gray) replacing galena (white). Both replacing sphalerite (dark). ×65.

d. Polybasite (gray) replacing and enclosing galena (white). Note irregular outline of the polybasite. ×65.

neutralization or reduction of the descending solutions when pyrite was precipitated out as radiating or botryoidal masses on the quartzose linings of the vugs. Following this, pearceite was deposited on the pyrite and quartz, forming the typical "secondary triangle ore" mentioned by Weed. Proustite was also deposited with the pearceite, but in accordance with the results obtained by Grout it represents a later stage when the relative silver concentration of the solutions was somewhat depleted. It is obvious from the experiments of Ravicz that arsenic must have been far more abundant in this deposit than antimony, for he has shown that the silver sulphantimonides are more readily precipitated than the sulpharsenides.

A similar and perhaps more striking illustration of the succession of supergene reactions was found on a specimen from the Tom Hendricks claim. This beautiful specimen, measuring some 4 inches in thickness and exhibiting a slickensided surface a square foot in area, was collected from the bottom of a winze 400 feet below the surface. Some time after the movement had taken place pyrite was deposited in irregular masses on the plane of fracture. Later, polybasite, indicating the prevalence of antimony in the supergene solutions, formed encrustations on the pyrite as well as elsewhere on the fissure surface. This would suggest that the pyrite was not directly responsible for the precipitation of the silver sulphantimonide. In one instance a group of polybasite crystals on the fault plane has later been covered by pyrargyrite exhibiting broad crystal faces almost ½ inch in diameter. Such large and well-formed crystals most certainly indicate deposition from solutions circulating, sluggishly perhaps, in an open fissure. This later precipitation of pyrargyrite is in accord with the experiments of Grout, which show that the sulpho salt precipitated depends on the relative concentration of the silver in the reacting solutions. The latest phase of supergene activity is indicated by the excellent rhombohedrons of dolomite which partially cover the fissure surface and dot the earlier pyrite and the silver sulphantimonides. The presence of the dolomite crystals is ample evidence of the total absence of acid solutions at that depth.

SUMMARY.

From a study of polished surfaces of the original ore the succession of the hypogene minerals was found to be as follows:

1. Quartz and pyrite.
2. Chalcopyrite.
3. Sphalerite.
4. Galena.
5. Polybasite ($9Ag_2S \cdot Sb_2S_3$), massive and without crystal form.

The criteria serving to establish the hypogene origin of the polybasite are:

1. The shattering of the pyrite first by zinc blende, later by galena, and finally by polybasite is a phenomenon foreign to supergene processes.
2. The polybasite has been introduced without showing any preference for cleavage directions in the galena, contacts between minerals, or other structural features.
3. The extreme diversity in size, shape, and distribution of the polybasite masses throughout the galena.
4. The absence of other silver minerals in the original ore such as native silver, pyrargyrite, and argentite, which are of supergene origin in the Neihart district.
5. The polybasite is associated with pyrite, zinc blende, and galena, which are unquestionably hypogene, and is found with these minerals from the 500-foot level to near the surface.

The succession of the supergene minerals occurring in the vugs and along the fracture planes is as follows:

1. Pyrite in radiating masses of octahedral habit.
2. Pearceite[10] ($Ag_{16}As_2S_{11}$) in the Moulton claim.
   Polybasite ($Ag_{16}Sb_2S_{11}$) in the Tom Hendricks claim.
3. Proustite (Ag_3AsS_3) in the Moulton claim.
   Pyrargyrite (Ag_3SbS_3) in the Tom Hendricks claim.
4. Dolomite rhombs in the Tom Hendricks claim.

CAMBRIDGE, MASS.
MASS. INSTITUTE OF TECHNOLOGY,

[10] Van Horn, F. R., Am. Jour. of Sc., vol. xxxii, p. 44, 1911.

DISCUSSION

AND

INFORMAL COMMUNICATIONS

UNDERGROUND WATER IN MIGRATION AND ACCUMULATION OF OIL AND GAS.

Sir: Mr. John L. Rich's recent paper on the "Migration and Accumulation of Oil and Gas" (ECONOMIC GEOLOGY, No. 6, Vol. XVI.) undoubtedly has been of great interest to students of this highly theoretical subject. A general discussion of this paper is desirable from geologists throughout the country in order to ascertain what is the present consensus of opinion in regard to the weight to be given to the various agencies causing migration and accumulation of oil and gas. In reading Mr. Rich's paper one is reminded of the long controversy which has existed among the ascensionists and descensionists in metalliferous geology. Is a similar discussion beginning among petroleum geologists?

Realizing the great need of substantial laboratory work to supplement our theories several investigators have recently performed elaborate experiments dealing with subsurface conditions. By such investigations our knowledge will be greatly extended, but I do not believe that work done with glass tubes under conditions which are not analogous to those existing in nature will add much to our knowledge.

In Mr. Rich's experiment in buoyancy (tube No. 1) a "layer" of oil-soaked sand was placed between two "layers" of water-soaked sand, the diameter of the sand grains being the same for all three layers, and tube No. 1 was set "aside to permit buoyancy to do its work." Commenting on the conditions under which the experiment was performed, Mr. Rich says: "In the case of tube No. 1 the conditions were no less extreme, for the dip was 90° and the sand was coarser than most oil sands, yet there was

no movement." Because the same sand was used for all three layers he believes the dip was 90°. To my mind he has essentially a zero dip. Experiments performed by Mills, McCoy, Johnson and others have shown that layers of water-soaked sand even of fairly coarse texture are rendered relatively impermeable to oil, therefore in packing layers of the same sand with different "pore filling" in the tube Mr. Rich has simulated horizontal stratification. Probably no petroleum geologist believes that segregation or accumulation of oil in commercial quantities can take place under conditions of zero dip with no agency to cause an initial movement and thus disturb the equilibrium. In Mill's experiments which were conducted on a much larger scale the oil was "introduced" into water-soaked sands of varying diameters. Buoyancy was effective in causing upward migration through the water-soaked sands. In this experiment initial movement was caused by the introduction of the oil at the bottom of the tank.

In tube No. 2, used to demonstrate the efficiency of circulating water in transporting oil, Mr. Rich has initiated movement by allowing water to escape from the bottom. In this experiment the direction of his water current is vertically downward. Vertical dips in oil fields are rare. Since water currents follow porous sandstone beds, unless fractures are present, the direction of the currents is generally more in a lateral than a vertical direction. The velocity which Mr. Rich used in this experiment is approximately ten times the maximum velocity given by Slichter's tables for sand grains of the same diameter under conditions of artesian flow common in nature.

Most laboratory investigators in subsurface geologic problems in drawing conclusions from their experiments have not seriously considered the geologic time factor. They have carefully tried to keep uniform conditions of temperature, pressure, velocity, etc., whereas in nature what really existed was a very complex series of changing factors operating over very long periods of time and producing in the end the results we now find in our oil fields. Another factor which needs emphasis is the original condition under which the oil, gas, and water existed in the sediments.

When compacting begins most geologists are agreed that the water and oil intimately mixed are forced into the porous rocks and that considerable gas is dissolved in the fluids. In nature this is the "starting point" of segregation. In the laboratory I do not believe sands saturated with such a mixture have been extensively used. In both of Mr. Rich's experiments these factors have been neglected.

A detailed discussion of the various examples cited by Mr. Rich to prove his theory is not practicable at this time. A critical examination of the published material and collaboration by many petroleum geologists in the various fields is necessary and highly desirable in order to determine the extent to which the various factors involved in segregation and accumulation have been operative. There are undeniable examples where "flushing" and downward hydraulic movement have been the chief agencies, but it is hard to believe that this process has occupied the major rôle as described by Mr. Rich.

Near the end of his paper Mr. Rich makes the statement:

> In the older fields, away from the coastal plains, as for example, in the fields of Wyoming, the geological history has been so complex and the stages of uplift, tilting and folding have been so numerous and so widely spaced in time that it would be futile to seek for a detailed explanation of the present arrangement of the oil pools in any postulated movements of the rock fluids at the remote time of original compacting.

He uses, however, the Big Horn Basin, Wyo., as his type example of flushing and downward hydraulic accumulation in an "artesian basin." Evidently Mr. Rich believes that the recent ground-water circulation has been the dominant agency in determining the present distribution of the oil and gas in this basin. Such an explanation ignores all the work of earlier geologic time, compacting, cementation, deeper burial by superposition of the Lance and Fort Union continental deposits, deformation, erosion and burial by continental deposits of later ages, etc., producing up dip movements of water causing the migration of oil into the anticlines before the present cycle of erosion exposed the oil sands to the "flushing" action of meteoric waters. The present ground-

water circulation has certainly modified to a slight extent the distribution of oil and gas in the Grey Bull and Torchlight fields and the waters in the Grass Creek field show admixture of non-saline waters, either of recent age or of post-Paleocene or post-Eocene age, with the saline waters of sedimentation.

In the Appalachian Basin, Mills and Wells have carried on extensive investigations of the oil-field waters. Their conclusions are not in accord with such a complete degree of "flushing" as postulated by Mr. Rich.

Another point which deserves emphasis is that the dilute or non-saline character of oil-field waters does not prove that they are the result of downward percolating ground water. Many of the sedimentary beds of our oil fields, including oil shales, show by their organic and lithologic character that they were deposited in brackish or non-saline waters under deltaic or coastal swamp conditions. It is therefore hardly reasonable to suppose that such water would even approximately correspond to the composition of sea water, although it is certainly interstitial water of sedimentation.

CHESLEIGH A. BONINE.

STATE COLLEGE, PA.

SOME NOTES ON IRON-DEPOSITING BACTERIA.

The writers became interested in iron bacteria in 1920, and decided to carry on some investigations with reference to their possible activity in brackish and salt water. During the summer of 1920 collections were made in Iowa and along the Rio Grande in Texas, and in 1921 in the Maracaibo basin of Venezuela. Unforeseen circumstances have arisen which make the completion of the work impossible, at least in the near future, so that it has been decided best to publish the meager results obtained, in the hope that they may be of some benefit to those interested in the subject.

There is no need here to discuss the iron-depositing bacteria and their habits from the standpoint of the bacteriologist. Har-

der,[1] Ellis[2] and others have fully described them and their activities in fresh water. To date there is little mention in the literature of the action of these organisms in brackish or salt water. It is in view of this fact that this article is presented.

In all samples of water from which iron was being deposited in quantity these bacteria were found. Only two samples, however, were taken from brackish water. These were secured from old stream beds which act as overflow channels for the flood waters of the Rio Grande in its highest stages. In the Resaca del Rancho Viejo, six miles northwest of Brownsville, Texas, much iron was being deposited in brackish water. A sample taken from the bed of the Rio Colorado eight miles southwest of Harlingen, Texas, contained much iron from moderately brackish water. In the sample from the latter locality only *Cladothrix dichotoma* was found, but these were abundant. In the collection made near Brownsville the bacteria present were *Leptothrix ocracea, Spirophyllum ferrugineum, Siderocapsa* sp. cf. *treubii* and *major, Cladothrix dichotoma* and *Crenothrix polyspora. Siderocapsa* and *Crenothrix* were abundant at this locality. The threads of *Spirophyllum ferrugineum* were old and dead but all had a generous coating of ferric hydroxide and no doubt took an active part in the process of deposition. The other forms were present in large enough numbers to indicate that they too played an active part in the deposition.

The bacteria obtained from the Resaca del Rancho Viejo were kept alive for nine months by addition of ferric acetate, the water being made slightly acid to prevent too rapid precipitation of the acetate. The water was not freshened in any way, in fact it became more salty by evaporation from the container, which was closed only by cotton.

Attempts were made during the past winter to cultivate cultures of the five types of bacteria mentioned and to transform these fresh-water forms to salt-water forms. They were placed in four containers, one of distilled water and to the other three

[1] Harder, E. C., Prof. Paper No. 113, U. S. Geol. Surv., 1919.
[2] Ellis, David, "Iron Bacteria," Frederic A. Stokes Co., New York.

had been added one-fourth normal, one-half normal, and full normal amounts of oceanic salts as given by Clarke.[1] All cultures were started at the same time and ferric acetate was added. All samples precipitated iron, and no more dead threads were found in the saline water than in the fresh water at the end of one month. There was, however, a much greater development of new threads in the fresh water than in the brackish and salt water. The development of new threads decreased with the increase of the amount of salt. At the end of seven weeks a noticeable change was brought about in the reduction of live bacterial forms in all cultures, and later it proved that a certain fungus (species unknown) which had been present from the first had developed to such a stage that the bacteria were killed. Up to this time the forms transplanted into salty water apparently were becoming adjusted to saline conditions. The amount of iron deposited by them from the acetate was sufficient to denote quite active life. The destruction of the bacteria by this fungus happened at a time when the streams and springs in Iowa were frozen, and no new forms could be obtained in amounts sufficient to work with. Consequently, no more data were obtained regarding the adaptation of these bacteria.

It is thought that fresh-water forms of iron-depositing bacteria can be transformed into salt-water forms. If this be true, can it be that there are living today salt-water forms which are inaccessible to study that are depositing iron under marine conditions, and, if so, did this same type of bacteria materially aid in the deposition of our great sedimentary ore deposits? If these bacteria are transformable it would be logical to conclude that this transformation is being carried on today by types passing down streams to bodies of water containing a high percentage of salt.

LLOYD NORTH AND I. J. BRIDENSTINE.

THE TEXAS COMPANY,
HOUSTON, TEXAS.

[1] "Data of Geochemistry," Bull. 695, U. S. Geol. Surv. p. 123, Analysis H.

REVIEWS

General Economic Geology. A Textbook. By WILLIAM HARVEY EMMONS. McGraw-Hill Book Company, Inc., 1922, 516 pp.

The appearance of the "Principles of Economic Geology" in 1918 established for the author a reputation as a textbook writer. The "Geology of Petroleum" in 1921 was a valuable addition to the many books covering that field. "General Economic Geology" possesses an equally high order of merit in the field it is intended to cover.

The preface states: "This volume is an introduction to the study of mineral deposits. It was prepared for students in colleges and technical schools who already have a knowledge of the elements of general geology and mineralogy. It embraces the geology of mineral fuels, structural materials, and other nonmetals and of the metals." The order of arrangement is such as to make it in reality three books in one, namely, the geology of coal, the geology of petroleum, and the geology of the nonmetallic minerals and the metals. The section on the geology of petroleum is a condensation of the author's volume on the "Geology of Petroleum"; that on the nonmetallic minerals and the metals is a condensation of his volume on the "Principles of Economic Geology." The high opinion of the latter volume held by the reviewer was set forth in considerable fullness in a review in ECONOMIC GEOLOGY in 1919. What was said at that time applies in the main to the third section of the present volume. J. B. Umpleby gave an equally appreciative review of the "Geology of Petroleum in Economic Geology" in 1921, which is likewise applicable to the second section of the present volume. The first section, that on the geology of coal, is, therefore, the only part upon which no judgment has yet been passed.

The first chapter headed "Introduction and Classification" is essentially Chapters I and II of the "Principles of Economic Geology." The diagram illustrating modes of ore deposition and the relationships of the processes affecting ore deposits which belongs here has for some unaccountable reason been placed on page 203 in the chapter on ore deposits formed by magmatic segregation.

The section on coal includes 93 pages and is divided into two chapters, the first of a general character and the second a description of the coal fields of North America. The first chapter gives a brief yet enlightening

account of the nature and origin of coals, the structural features of coal seams, and the chemical characteristics of coals. The description of the coal fields is a well-digested resumé of the various North American coal fields. A criticism of this section is the failure to mention important coal fields in other continents. In the section on petroleum, the account of the distribution is not limited to North America, but includes with a fuller description of the North American oil fields a briefer description of the principal oil fields of the rest of the world. Why the elementary student should know about the oil fields of the world and be restricted in his knowledge of the occurrence of coal to North America is not apparent.

The section on petroleum includes 98 pages and is also divided into two chapters, corresponding to the twofold division of the coal section. The presentation of the subject follows very closely that of the "Geology of Petroleum," so that the 593 pages of the latter volume have been reduced to 98 pages. The condensation has been accomplished more by the elimination of whole paragraphs than by a reduction through rewriting. Among the topics considered in the first chapter are the indications of oil, its properties, its geologic associations, its origin and mode of accumulation, and petroliferous provinces. The second chapter is largely a description of the oil fields of the world, but at the end it has a section on oil shales and one on solid bitumens and bituminous rocks. These two topics are included in the "Geology of Petroleum" under the heading of indications of oil and associated materials. In line with recent greater interest in oil shales that topic receives a little fuller treatment than in the "Geology of Petroleum."

The section on mineral deposits is by far the largest and includes 298 pages as compared with 588 pages in the "Principles of Economic Geology," of which it is a condensation. The outline of this section follows closely the sequence of presentation of the subject in the earlier book. Again the reduction in space has been accomplished by the elimination of whole paragraphs more than by shrinkage through rewriting. The nineteen chapters dealing with the general principles of economic geology of the advanced work are herein reduced to four chapters, but the same topics are discussed in the same sequence with but two exceptions. The chapter on primary ore shoots and the section on topographic expression of deposits are omitted. The complete omission of a discussion of primary ore shoots must have been inadvertent rather than intentional.

A departure in the descriptive part of the section is the consideration of the nonmetallic deposits ahead of the metallics. In the "Principles of Economic Geology," the former are treated in 56 pages constituting the last chapter. In the new book their treatment has been expanded to seven chapters totaling 97 pages. The wholly inadequate consideration

of the nonmetallics in the "Principles of Economic Geology" was commented on in its review. "General Economic Geology" remedies that defect. The additional space devoted to the nonmetallics is in part accounted for by the inclusion of a number of additional substances, as prepared stone roofing, marl, gravel, and crushed stone, sand, sand-lime brick, calcium chloride, epsomite, sodium carbonate, iodine, halloysite, lithographic limestone, and Iceland spar.

The description of the deposits of the various metals is divided into one less chapter by combining gold and silver into one chapter. Otherwise the treatment is essentially the same as in the "Principles of Economic Geology." There are separate chapters on the major metals—iron, copper, gold and silver, zinc and lead,—and a chapter on twenty-one miscellaneous metals. Like the section on coal, this part of the book is confined largely to a description of North American metalliferous deposits. Again it is not clear why in the discussion of mica the student is told that India produces much the largest part of the mica output, whereas in the case of tin he should be content to know that the tin deposits of the United States are small instead of being told where the greater part of the tin output comes from. The seemingly fortuitous sequence in which the miscellaneous metals are taken up in the "Principles of Economic Geology" was criticized in the review of that volume. The justification of that criticism is demonstrated by the considerably changed sequence, but still without obvious system, in "General Economic Geology."

To sum up the evaluation of the volume, the reviewer need paraphrase but slightly his characterization of the "Principles of Economic Geology." The author has kept the purpose of the book in mind throughout its preparation. The treatment of each subject is direct, concise, and thorough. Maps, cross sections, and other illustrations are used wherever conducive to clearness. The book is distinctly usable as a textbook in collegiate and technical school courses in economic geology and will serve in addition a wide use as a handy elementary reference work for all interested in the geology of the useful materials of the earth's crust.

JOSEPH T. SINGEWALD, JR.

The Coal Catalogue Combined with Coal Field Directory for the Year 1922. 1,350 pages. Keystone Consolidated Publishing Company, Inc. Pittsburgh. $10.00.

This is the third edition of the Coal Catalogue. Some new material has been added, many of the articles have been rewritten, and the various tables have been revised and brought up to date.

Part I. contains articles on the geology of coal and various features of its production, storage, and distribution. The portions dealing with geol-

ogy are not enlightening. A table of geological time is given which conforms to no recognized standard and might well be omitted. The article entitled "The Geology of Coal" is devoted entirely to quotations chosen with little discrimination, and in large part from antiquated reports. No final summation is attempted and the net result is to leave the lay reader in more or less of a quandary. A short summary from some standard text would be far more effective. The remaining articles of this section are more adequate. They deal with the more technical features of the industry: the preparation of coal, its storage, sampling, composition, methods and mediums of distribution and export. Some valuable tables are included on the fusibility of the ash and the specific gravity of domestic coals. A list of coke and by-products ovens is also introduced.

Part II. deals with three of the classifications of coal. The most valuable of these is the second, which is based upon the uses, and qualifications for the various uses are designated. Appended to each is a list, by states, of the seams producing coal fitted for that use together with references in Part III. for a description and analysis of the seam and its operators.

Part III. takes up the coal horizons of each state, giving maps, detailed sections, analyses and a general description of each basin. A list of the mines by seams is included, which furnishes the name of the company, general office address, county, railroad, and shipping point. Then follows an alphabetical directory of the mines giving, in addition to the location and officers, information on the type of coal produced and mining methods used.

Part IV. consists of lists of national and local organizations interested in the coal industry and of the sales offices of the several companies.

The Coal Catalogue is quite well bound, fairly well printed, and free from glaring typographical errors. The index might be considerably improved, as might the arrangement of material under the Classification of Coals according to Use. The interspersion of advertising is at times confusing and unfortunate.

The Catalogue is, of course, intended as a reference volume for those interested in the distribution and purchase of coal and, as such, is of the highest value.

THOMAS B. NOLAN.

Potash. New Ed. Revised and Enlarged, by SIDNEY J. JOHNSTON, B.Sc. (Lond.), A.I.C. Imperial Institute. John Murray, London, 1922, pp. x+122, 6s. net.

This volume is one of a series of monographs issued by the Imperial

Institute, London, on mineral resources with special reference to the British Empire. "The object of these monographs," as stated in the preface, "is to give a general account of the occurrences and commercial utilization of the more important minerals, particularly in the British Empire. No attempt has been made to give details of mining or metallurgical processes." The object above stated is amply fulfilled in this book, which may be regarded as a most valuable handbook on the subject of potash.

The introduction, which constitutes the first chapter, contains a brief summary with tables of the imports and exports of potash by the United Kingdom and of the output of potash of the world and of the United States. This is followed by ten chapters setting forth types of occurrence or sources of potash. These are sufficiently suggested by the chapter headings as follows: Deposits of Soluble Potash Minerals; Salt Lakes and Pans; Potassium Nitrate Deposits of Mineral Origin; Potassium Nitrate Deposits of Organic Origin; Sea Water as a Source of Potash; Insoluble Potash Minerals; Flue Gases as Sources of Potash; Vegetable Sources of Potash; Residue from Beet-sugar Manufacture; Animal Sources of Potash.

Each chapter is a discriminating discussion of its subject. Reference is made to each country in which potash occurs or is produced, and the mode of occurrence and the methods of production are succinctly outlined. Sufficient tabular matter is introduced to illustrate clearly the chemical character and the production of such potash-bearing materials as have economic importance.

In view of the virtual monopoly so long held by the German potash syndicate it may be a surprise to many readers to note the number of countries in which potash activity has been taking place, and the number of sources from which potash has been commercially derived.

A valuable feature of the book is the reference list at the end, which comprises 179 titles. These are indicated in the text by a convenient device which does away with footnotes. A number of the works listed contain bibliographies.

G. R. MANSFIELD.

SOCIETY OF ECONOMIC GEOLOGISTS

This department has been established for the official communications of the Society of Economic Geologists whereby the affairs of the Society such as notices, minutes, titles of papers, elections, etc., may be brought regularly to the attention of its members.

Members resident in Europe or who may be visiting there in August should attend the International Geological Congress to be held in Brussels from August 10th to 19th. The excursions cover the period from July 31st to August 31st. Messrs. R. A. F. Penrose, Jr., George Otis Smith, and Horace V. Winchell are the delegates of the Society to this meeting.

The Society has accepted the invitation of the American Institute of Mining and Metallurgical Engineers to hold a joint session with them at San Francisco, California, from September 25th to 29th inclusive. Members will remember the success of the meeting with the A. I. M. E. at Wilkes-Barre, Pennsylvania, last September. A joint technical session on Economic Geology will be one of the features of the meeting. Papers by members intended for presentation at the time may be sent either to the Secretary or to Mr. B. S. Butler, Chairman of the Publications Committee, Box 277, Calumet, Michigan.

A membership ballot was sent out the first of June. Members will kindly note that this must be returned to the office of the Secretary prior to October 1st.

SCIENTIFIC NOTES AND NEWS[1]

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice

D. F. Hewett, of the U. S. Geological Survey, has returned to Washington after extended field work.

Pentti Eskola, of Finland, is collaborating in the work of the Canadian Geological Survey this summer.

C. W. Knight, associate provincial geologist of Ontario, is investigating the South Lorrain silver area.

George H. Garrey has returned to Tonopah.

A. F. Buddington is working in the Wrangell district, southeastern Alaska, for the U. S. Geological Survey.

George Otis Smith, Director of the U. S. Geological Survey, recently addressed the Public Committee on Coal in New York on the relation of mine employment to mine production.

Frank D. Adams, professor of geology and dean of the faculty of applied science at McGill University, Montreal, is chairman of the Canadian Advisory Council for Scientific and Industrial Research.

Waldemar Lindgren is making a special report on the geology and ore deposits of the Bradshaw Mountain for the U. S. Geological Survey.

D. D. Condit has returned from India, and expects to leave again for India late in August.

Kirk Bryan, of the U. S. Geological Survey, is in the Yosemite National Park, California, to assist the National Park Service in developing a water supply for parts of the park.

F. J. Alcock, of the Canadian Geological Survey, is investigating the formations of the Elbow Lake mineral area in northern Manitoba.

C. E. Siebenthal is in the Tri-State field to complete his study of the geology of the Oklahoma and Kansas sections of the field, a work started by him before the war.

E. S. Moore has resigned the position of Dean of the School of Mines and Professor of Geology and Mineralogy of the Pennsylvania State College to accept the position of Professor of Economic Geology in the University of Toronto.

A. H. Brooks is accompanying the Hon. C. H. Huston, Assistant Secretary of Commerce, in an investigation of the fishing and fur-seal industries of Alaska. He will stop on the Siberian coast and return via the Philippines.

A. S. Eakle, professor of mineralogy at the University of California, has been visiting mining districts in Nevada.

Arthur Eaton has sailed for Europe to attend the International Geologic Congress at Brussels as delegate from the American Association of Petroleum Geologists.

A. P. Coleman, who has been thirty years on the geological faculty of the University of Toronto, has resigned his position as head of the Department of Geology and Dean of the Faculty of Arts.

A. G. Burrows, of the Ontario Department of Mines, is making an examination of the Porcupine gold area, including the underground workings of the mines.

Edwin Berry has gone to Portugal.

Russell D. George, state geologist of Colorado, has received the degree of LL.D. from McMaster University, Toronto.

M. R. Campbell is in Wyoming, examining coal claims for the land classification board.

R. C. Wells is coöperating with L. C. Graton in a study of the formation of the copper ores in the vicinity of Calumet, Michigan.

C. R. Longwell and Alexander Stepanoff are at Newcastle, Wyoming, where they are carrying on work in oil geology.

J. D. Sears and his geological party have moved west of Little Snake River, in Moffat County, Colorado.

F. L. Hess, of the U. S. Geological Survey, has returned to Washington after a field trip in the West.

C. P. Ross is doing work in the Aravaipa district of Arizona.

Charles B. Croner is in southern Utah making a geological survey of the Goldstrike mining district.

J. A. Bancroft, of McGill University and assistant manager for the Granby Company at Anyox, British Columbia, is making a number of examinations in the Stewart district for his company.

L. H. McLearn, of the Canadian Geological Survey, is investigating the Triassic and Cretaceous formations along the Peace River, where drilling for oil is now being undertaken.

W. Spencer Hutchinson has been appointed full professor of mining engineering and put in charge of the option in mining at the Massachusetts Institute of Technology.

Olaf P. Jenkins is in charge of geological investigations of the coal fields of Whatcom and Skagit counties, Washington, for the State Division of Geology.

W. S. Bayley, of the University of Illinois, has been elected President of the Illinois State Academy of Science.

G. S. Hume is heading a party this summer for work in British Columbia under the Geological Survey of Canada. His season's work will be confined to the district adjoining Fort Norman to the north.

Charles Camsell, Deputy Minister of Mines and head of the Geological Survey of Canada, was granted an honorary degree at Queen's University.

Lucien Beckner, consulting geologist of Winchester, Kentucky, was elected president of the Kentucky Academy of Science at its annual meeting.

F. H. Moffit is in the Chitina region, Alaska, for the U. S. Geological Survey.

A. E. Fath is in Europe, on leave of absence from the U. S. Geological Survey, for several months.

J. J. O'Neill, of Montreal, will carry out extensive geological work during the summer in the Hay River region, adjacent to Great Slave Lake, for the Geological Survey of Canada.

R. S. Knappen, of the University of Kansas, is in the Big Horn Basin, Wyoming, engaged in oil and gas work for the U. S. Geological Survey.

W. H. Emmons is in Tennessee continuing his survey of the Ducktown mining district for the U. S. Geological Survey.

M. Y. Williams, of the University of British Columbia, will continue geological work in the Fort Norman field for the Canadian Government during the present summer.

G. R. Mansfield, of the U. S. Geological Survey, has been investigating the potash fields of Texas and the borate fields of California.

P. S. Smith, of the U. S. Geological Survey, is in Alaska making geologic investigations in the region tributary to the Alaska Railroad.

J. B. Mertie, Jr., of the U. S. Geological Survey, is investigating the gold deposits of the Fairbanks and Rampart districts, Alaska.

Elmer H. Finch, formerly with the U. S. Geological Survey, is in Central America for several months for the purpose of making geological surveys of prospective mineral lands.

The Deutsche Geologische Gesellschaft is holding a meeting in Breslau, from the 29th of July to the 8th of August, to which geologists and geological societies of other countries were invited. The principal topics under discussion are:

1. The reciprocal tectonic relations between intrusive masses and their surroundings.
2. The geological relations between Fennoscandia and Central Europe.
3. International geological maps.

Alan M. Bateman has left for a short trip to the Utah Copper Company and Nevada Consolidated Copper Company.

M. R. Campbell is surveying the Deep River coal field for the U. S. Geological Survey.

C. E. Van Orstrand is making temperature tests in some of the oil fields in Ohio, Indiana, Illinois, Wyoming, Montana, California, and Oklahoma. He expects to return about September 15.

John T. Reid has returned to his office in Lovelock, Nevada, for the summer.

W. A. Tarr recently returned from the Lead Belt in southeastern Missouri, where he had a class of geological students from the University of Missouri. He also studied certain problems relating to the origin of the various ores in that district.

Willet G. Miller is in South Africa.

E. K. Soper, Manager of the Trinidad Tarouba Oil Development Company, which also operates the Vistabella Manjak Mine in Trinidad, has returned from Trinidad to New York. His address is Room 2306 Sinclair Oil Building, 45 Nassau Street, New York City.

Everett Carpenter, Consulting Geologist of Winfield, Kansas, who has undergone two major operations since March 1, is again able to resume his work.

Carnegie Institute of Technology at Pittsburgh has been selected by the United States Naval Academy at Annapolis to give advanced courses in Metallurgy to its graduate officers. F. F. McIntosh, Associate Professor in Metallurgy, will supervise the studies of the Naval officers.

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